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HEAVY MILITARY ELECTRONICS DEPARTMENT

SYRACUSE, NEW YORK

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SIGNAL PROCESSING AND DATA ANALYSIS SERVICES FOR U. S. NAVY UNDERWATER SOUND LABORATORY.

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Prepared for

U.S. Navy Underwater Sound Laboratory
Fort Trumbull
New London, Connecticut

(In response to RFQ 15 N00140-68-Q-0120) new

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HEAVY MILITARY ELECTRONIC Systems ~~DEPARTMENT~~ SYRACUSE, N. Y.

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GENERAL ELECTRIC SONAR R & D PROGRAMS

February 20, 1968

Hybrid Beamformer

A digital beamforming technique has been developed for the C/PA program employing a combination of time delay and phase steering (hence, hybrid). We feel this technique to be superior in cost and performance features for planar arrays as well as other array configurations.

Medior Goast

This is a non-parametric signal processing technique for active ASW sonars. Its features are that (1) its performance is not degraded by range and doppler spreading of echoes, and (2) it presents a normalized noise background to the display, even when noise and/or reverberation is non-stationary and non-gaussian.

Medium Simulation Studies

The effects of a randomly varying multipath environment on the detection performance of LFM signals and processors has been studied using Monte-Carlo computer simulation. Work is continuing on expansion to other signals and processors, including Medior/Goast.

Data Normalization

Several techniques have been developed for the normalization of the output noise of active sonar signal processors, to provide a better match to display dynamic range or CFAR to sonar computers. Most of these are digital and include normalization in time, doppler, and space (beam-to-beam).

DIMUS

Under the BQR-7 Program, several advancements have been made in DIMUS beamforming for passive sonar, including display spoke suppression, automatic target following, spatial (beam-to-beam) normalization and variable averaging time displays.

26 MARCH VISIT
JIM KALITTA HMED
456-7030
COURT ST. SYERADON

Submarine Signature Studies

Under contract to ONR, detailed spectral analyses of submarine signatures have revealed some interesting, heretofore unknown signature characteristics.

C/PA Data Processing

Specific techniques for processing active signal processor output data have been developed under the Conformal-Planar Array (C/PA) Program. The objective of this work has been to reduce the high data rates inherent in a system with a large number of receiving beams. Both single ping and multi-ping processing schemes were under development at the time work was stopped. These techniques, it is felt, are of general interest for future active systems.

Computer Aided Detection

Under contract to Exploratory Development, techniques are under development for the automatic processing of active sonar signal processor output data. Emphasis has been given to sea data obtained with the SQS-26 system.

Adaptive Spectral Spatial Processor (ASSP)

An adaptive beamforming technique has been developed for use in the spectral analysis of passive signatures. The beamformer is capable of adapting in an optimum way, to non-isotropic noise fields, one frequency at a time. Time compression is used so that an entire band of frequencies can be covered in real time. This is ore implementation of the Mermoz optimum beamformer.

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SECTION I
INTRODUCTION

This Proposal documents the capability of the Heavy Military Electronics Department of the General Electric Company to perform signal processing and data analysis services for the U.S. Navy Underwater Sound Laboratory. Specifically, personnel experience, previous program background, and the appropriate facilities are described in detail.

The personnel of this organization have contributed to the success of many Navy programs employing modern signal processing and data analysis techniques. This experience includes conceptual and experimental work involving both active and passive processing systems, analog and digital instrumentation, and surface ship and submarine platforms.

Section II of this Proposal describes the work done on several programs similar in nature to the services required by USNUSL as outlined in RFQ N00140-68-Q-0120. Included are descriptions of work related to computer-aided detection, DIMUS, and the AN/SQS-26. These program summaries indicate the combination of statistical data analysis and modern analysis tools to simulate, analyze, and synthesize signal processing schemes. The full scope of data analysis problems have been encountered, starting with experiment design and sea test through data reduction, analysis and presentation.

Section III includes resumes of GE personnel who have been selected as candidates to provide the services to USNUSL. It may be seen that they possess considerable experience in data analysis and signal processing. To indicate the breadth of background that is available, a bibliography of reports and papers related to sonar signal processing and data analysis, and written by HMED personnel, is included in Section V.

Section IV describes the equipments and analysis facilities available to accomplish work tasks. These include analog and digital hardware and software. Hardware and software are described to A/D convert, format, edit, process and display data. Included are examples of unique computer usage to generate useful data presentations. These descriptions, along with the aforementioned program outlines, demonstrate the results of creative and efficient usage of quality facilities.

SECTION II
RELATED PROGRAM EXPERIENCE

Since 1950, the Heavy Military Electronics Department (and its predecessor Departments) has had sole responsibility for the Company's efforts in research, design, development and delivery of sonar and related acoustic equipment, except for airborne sonar and sonobuoy responsibility, which rests with the Aerospace Electronics Department.

Knowledge and experience that has been obtained on past programs could in many cases be directly applicable to tasks involving analog and digital data analysis, computer simulation of processes and statistical analysis. A resume of appropriate related programs is presented in this Section.

A. AN/SQS-26 PROGRAMS (NObsr 75240, NObsr 93137 and NObsr 77625)

For the past five years, the Heavy Military Electronics Department has been actively engaged in programs relating to the AN/SQS-26 Active Surface Ship Anti-Submarine Sonar. The Department has had a major share of the responsibilities for this program from its inception through the development, design, manufacture, test and delivery of the total system. Much of the experience gained is directly related to acoustic signal generation and processing, digital data handling, and operation of equipment in an operational shipboard environment.

1. CODED WAVEFORM STUDIES

The objective of this program was to determine the relative detection capabilities of various waveforms under reverberation and noise limited conditions. Greatest emphasis was given to the effect of distortion of high resolution signals due to platform motion and multiple echo arrivals. Types of waveforms considered were:

1) Band-limited pseudo-random noise pulse
2) Pseudo-random pulse
3) Linear FM pulse
4) Quadrature FM pulse
5) Simple tone pulse

The performance capabilities of these waveforms were evaluated with actual echoes obtained at sea, using both laboratory signal processing equipment (see Section IV, I, for description) and computer simulation of various signal processing configurations.

This work was reported at the U. S. Navy Underwater Acoustics Symposium, November, 1966.

2. SEA DATA ANALYSIS

A concurrent study was conducted to obtain quantitative measurements of the multipath structure of signals traveling over a one-way path between a surface ship and a submarine. Short-tone pulses 2 milliseconds long were transmitted to obtain the time spread, and long-tone pulses 0.5 seconds long were used to obtain the frequency spread. The time-spreading data was analyzed in the laboratory, with the resulting data for each pulse being punched onto IBM cards. The computer was then used to produce overall results for ensemble averages using approximately 100 pings. The 0.5-second CW data was digitized and then spectrum-analyzed using the Fourier Transform of the sampled autocorrelation function.(Note: Fast Fourier Transform programs are presently available at HMED, which would substantially lower the processing time that would be required for digital spectrum analysis.)

This work was reported at the U. S. Navy Underwater Acoustics Symposium, November, 1966.

3. CODED PROCESSORS

Various correlation processors for the LFM signals were evaluated using "live" as well as simulated signals. Among those evaluated were:

1) Clipper correlator
2) Linear correlator
3) Detector integrator
4) TIMAC (a delta modulation technique)
5) Multi-bit correlator
6) Clipper correlator followed by level control
7) Correlator with incoherent integration of the output to reduce bandwidth to match the medium.
8) Correlator with detector and peak hold circuit to reduce output bandwidth for display matching.

Many high time-bandwidth coded waveforms recorded over both one-way and two-way propagation paths were digitized over a five-second range interval. These were computer-analyzed to note the degradation on coherent processing due to time and frequency spreading. Various signal processing schemes were visually compared for the same sea data returns. In certain cases, laboratory-processed sea data was compared with the computer-processed data for the same returns.

4. CW RECEIVERS

Research and development has been performed in the area of CW Receivers as applied to systems such as the AN/SQS-26, wherein improvement is desired in both the bottom bounce and surface duct mode of propagation. An adaptive notch filter technique has been devised for pre-whitening of the time variable reverberation spectrum and for continually optimizing detection of low and high doppler targets. In addition, a constant variance AGC loop was developed to reduce the dynamic range problems of CRT displays.

A paper on the adaptive notch technique was presented at the U. S. Navy Underwater Acoustics Symposium, November 1966.

5. DISPLAYS

A core memory storage display has been developed on internal funds to provide a bright, steady history presentation to the sonar operator. Digital memory and a large dynamic range in intensity, coupled with the flexibility of digital storage, will improve target detectability and reduce operator fatigue.

6. PRE-SELECTOR STUDY FOR AN/SQS-26 (XN-2) SONAR DATA

This study was conducted to determine the nature of the data from the AN/SQS-26 (XN-2) Sonar signal processing equipment, to predict the usable signal characteristics and to develop methods for automatic pre-selection and encoding of the data prior to its transmission into an AN/USQ-20 computer (or equivalent) for further processing. The computer-processed information was utilized to raise or lower the threshold for the purpose of optimizing the data handling rate. Specifications were prepared and submitted for a service test model of the pre-selector sonar signal processor. This

equipment was built by the Heavy Military Electronics Department for testing with sonar data taken with the AN/SQS-26 (XN-2) equipment aboard the USS Wilkinson during the December 1963 sea exercises. The Department also participated in developing and writing the programs that were used with the AN/USQ-20 Computer.

B. AN/BQR-7 DIMUS SIMULATION

A simulation of the AN/BQR-7 DIMUS passive receiver system using recorded sea data inputs has been performed. This program was undertaken to provide a high degree of confidence in the performance of a system without resorting to the construction and sea testing of an equipment. Verification and refinement of system parameters to perform against actual sea conditions is a valuable asset. A number of possible improvements observed after equipment has been constructed are often omitted because of cost considerations. These changes can be made if a simulation is used to uncover the factors before the equipment is designed.

Data for the AN/BQR-7 DIMUS was collected at sea by magnetic recording of all hydrophone signals on a multichannel recorder. These recordings were then played back in the laboratory, digitized and recorded on digital tape.

The digital tapes produced from the sea tapes are processed through a commercial digital computer simulation of the DIMUS system. Digital simulation of DIMUS on a commercial digital computer can be exact, since the DIMUS system is also all digital.

The digital output is available in several forms including a CALCOMP plotter output closely resembling the actual system output, Figure II-1. Figure II-2 is a block diagram of the simulation system.

C. COMPUTER-AIDED DETECTION (NObsr 93298 and NO 0024-67-C-1187)

The need for handling larger quantities of sonar receiver output data than can be conveniently displayed has arisen due to increasing resolution in range, doppler and angle of active shipboard sonar systems. This has led to the investigation of techniques of data processing for reducing the data rate to that acceptable by displays. The Heavy Military Electronics Department has been working on a study of this subject.

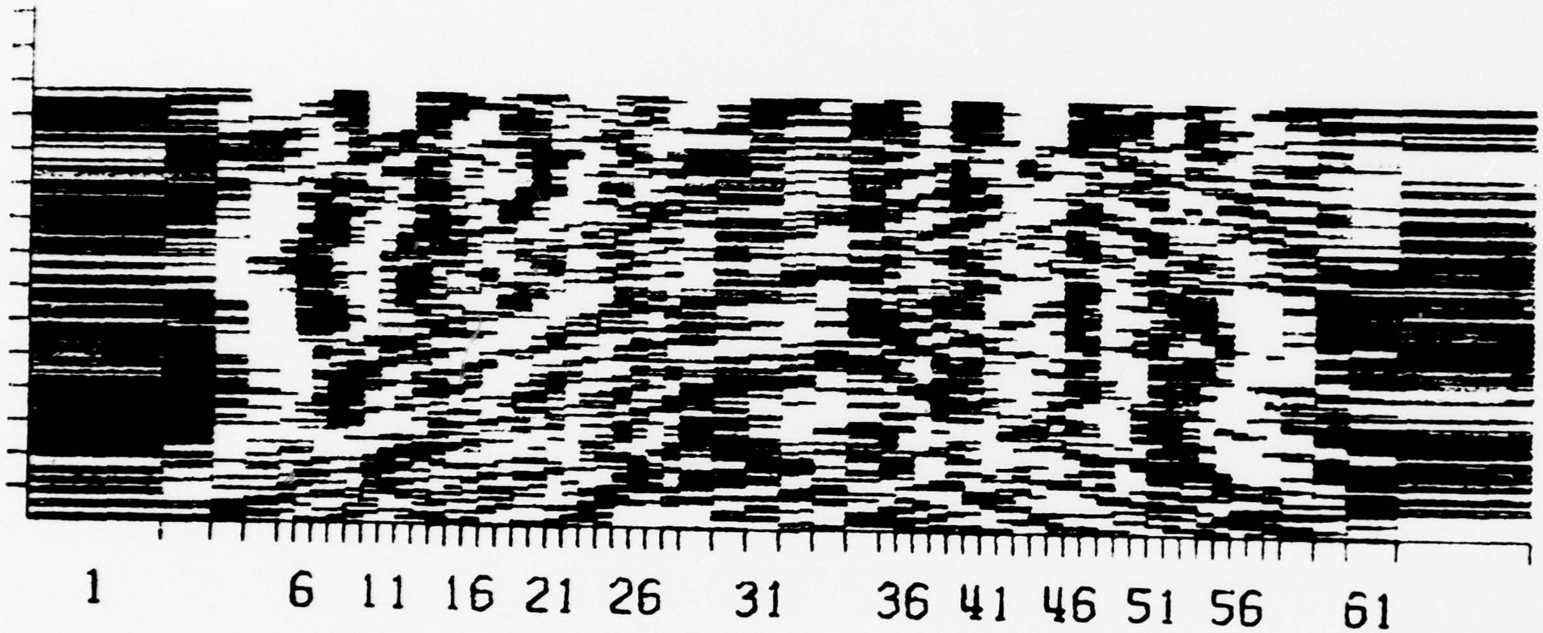


Figure II-1. Simulated DIMUS Display

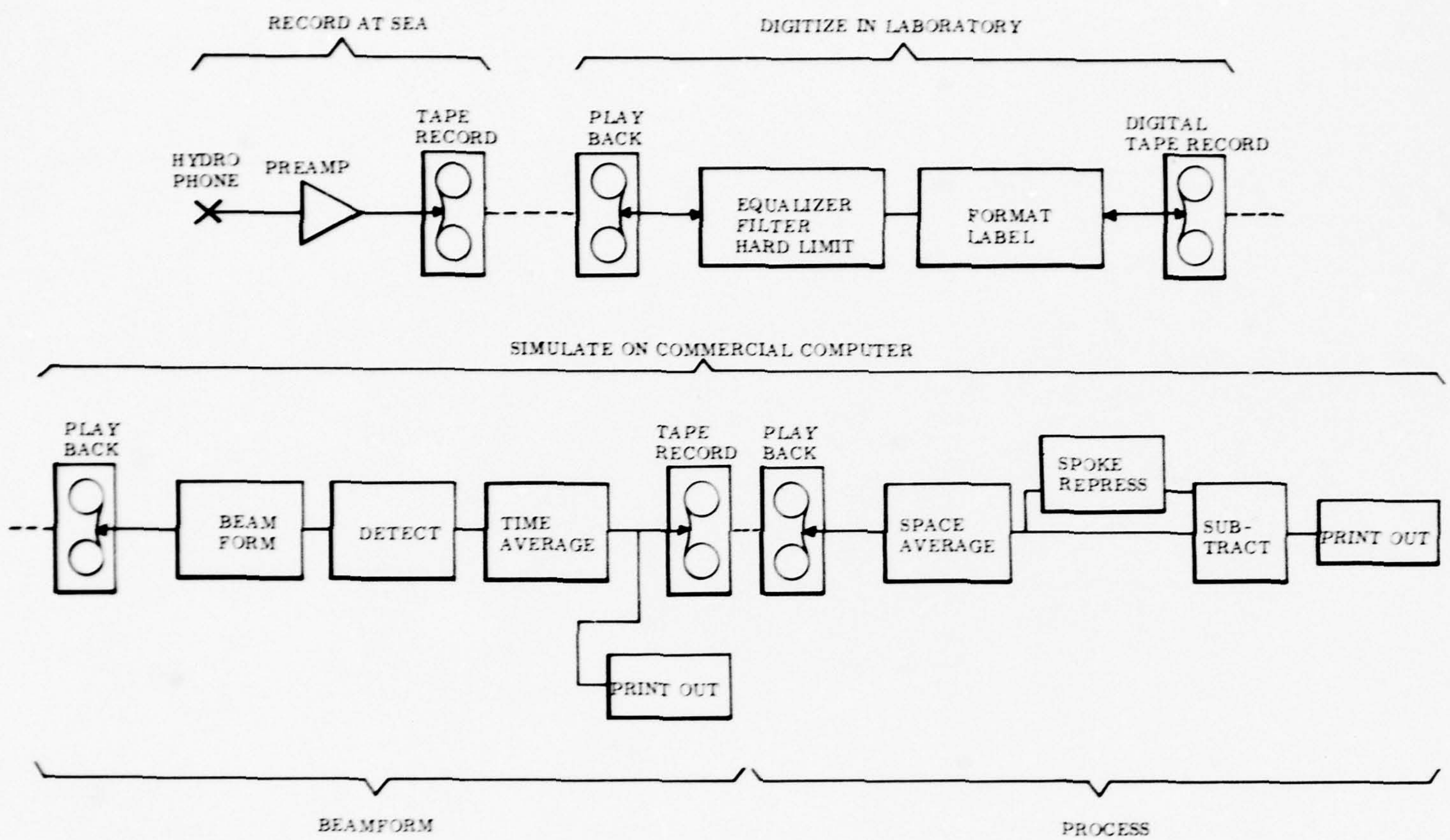


Figure II-2. AN/BQR-7 Simulation System

Data from several sea tapes has been digitized and processed through digitally simulated linear correlators and energy detectors. The analysis of the correlator output includes machine contour plots of the amplitude vs. time and frequency surface and statistical analysis of the output surface. Figures IV-3 and IV-4 in Section IV show typical computer outputs.

D. DATA ACQUISITION AND ANALYSIS FOR AN/SQS-26 CX R/M TEST

Several modes of the CX system were to be tested periodically by injection of signal and noise voltages at the input ports with the noise levels and signal-to-noise values specified. The outputs of certain processors were to be monitored and the output SNR values determined. "Baseline" system SNR gains were established at the start of the test and allowable degradations from baseline for the various operating modes had been specified. Thus, the main purpose of this data analysis program was to provide accurate and verifiable measurements of overall CX system degradation at specified times during the R/M (Reliability/Maintainability) test program.

Analog tape recordings were made of both input and output signals during each test. These tapes were later converted and digital tapes were produced for use with the IBM 7094 computer. Computer analysis of the digital tapes resulted in a complete listing of the test results.

E. SIMULATION OF RANDOM MEDIUM (INTERNAL FUNDS)

As a result of AN/SQS-26 signal processing experience, plus programs conducted on internal development funds, a capability is evolving within the Heavy Military Electronics Department for the computer simulation of the entire flow of a sonar signal from the transmitter through a randomly varying medium to the receiver output. The method also provides for the simulation of interference. This has proven to be of special value in permitting a more realistic and rigorous evaluation of various waveforms and processors than is possible analytically, and a more controlled evaluation than has been possible at sea. The received signal is modeled as a multiplicity of replicas of the transmitted signal with random time delays and doppler shifts. Reverberation is modeled in a similar way; only the statistical distribution from which time delays and dopplers are selected are different than for the signal.

The computational techniques and many of the existing programs are directly applicable to any active sonar processor. A paper on this work will be presented at the U. S. Navy Underwater Acoustics Symposium in November.

F. NADC ADAPTIVE NOTCH STUDY (N62269-67-C-0538)

The objective of this program was to estimate the reverberation spectra of sonar data and to design an adaptive notch filter to pre-whiten the data background. To estimate the reverberation spectra, time records were digitized from recorded analog data and the frequency content of the reverberation power obtained by transforming the data to the frequency plane using a Fast Fourier transform algorithm. Ensemble records of data were also analyzed. Digital spectrum analysis and digital filtering were both performed on the data to obtain amplitude as a function of time-frequency for the data records analyzed. Weighted and non-weighted spectra were analyzed to obtain a measure of the effect of sidelobe supression using various weighting functions.

G. C/PAS (CONFORMAL PLANAR ARRAY SONAR) (NObsr 93022)

The Heavy Military Electronics Department has contributed extensively to several areas of this program. Two of these areas, signal processing and data handling, are described below.

1. SIGNAL PROCESSING

The work to date on this aspect of the C/PAS problem has been devoted primarily to conceptual studies, block diagram design and selection of many of the more pertinent factors to accommodate a large variety of signal waveforms. Much effort has been devoted to efficient equipment design to accommodate a large number of receive beams for the signal processing. In general, the transmissions to be handed by the processor are short pulse surface duct and wide and narrow band bottom bounce. Signals must be handled over wide ranges of potential target doppler. The dominant philosophy in the signal processing has been the coherent pre-detection processing and post-detection non-coherent combining of received signals.

The initial concept for the signal processing resulted in a design that had specialized processors for each of the modes - e.g., surface duct, wide and narrow band bottom bounce and passive. The design used a hybrid of analog and digital techniques and entailed several transitions.

The emphasis has now shifted to all digital techniques for signal processing. In connection with the Experimental Ship System portion of the C/PAS program, the emphasis has been on providing an active signal processor that is capable of accommodating a large variety of signal waveforms on a flexible basis. As a result, the concept for the processor has been modified to handle all the waveforms by use of the same digital stored reference correlators. Design studies are currently in progress to further define the exact configuration. The same design will also be applicable to the prototype C/PAS signal processor in particular if the selection among several waveforms is contemplated in the operational sonar. The design of the passive signal processor is also based on digital techniques.

2. DIGITAL DATA HANDLING

The extremely high data rates of the C/PAS system demand automatic means of handling the data. This will include processing all of the data from the signal processors for detection of targets on the basis of single and multiple pings; classification of these targets into the classes of threat and non-threat; and the tracking of these targets. Since the system is so extensive and complex, many of the tasks that previously had relied on inputs from an operator, such as selection of optimum search patterns, will now be programmable within the data handling computer.

One effort of the data handling program has been to perform post-detection data normalization. This normalization will provide CFAR properties at each beam output so that data from different beams can be processed efficiently, both on a beam-to-beam basis and a multiple ping basis. A program has been under way to analyze un-normalized and normalized experimental SQS-26 data in an effort to determine the effects of post-detection normalization on detection and to measure the statistics at the data normalizer input and output. Computer simulations of the data handling/signal processing functions have been made.

Computer programs are available from this project, which calculate rank statistics, density functions, distribution functions and various measures of signal-to-noise ratios. A CALCOMP display of processed data output is shown in Figure II-3.

H. DOWN RANGE EXPERIMENTAL RADAR SITE DATA ANALYSIS

Extensive data analysis has been performed by HMED on experimental data obtained from the Trinidad Radar Site. From this data analysis program, several computer software programs were developed. Computer programs developed and available at HMED include the following:

1) Quality Check Programs
   a) Tape copy, compare, and dump
   b) Binary tape dump
   c) Calibrations and decimal dump
   d) Calibration averager
2) Initial Calculations
   a) Unpack real time
   b) Unpack playback
   c) Plot position data R.A.E.H.
3) Editors
   a) Edit any of 22 variables
   b) Time segment edit
   c) Merge
   d) Data smoother
4) Plot Program
   a) Combination Averager & Time Plots
5) Analysis Programs
   a) Statistics without nulls
   b) Statisitcs with nulls
   c) Autocorrelation and power spectrum
   d) Cumulative distribution
   e) Separation velocity
   f) Prediction
   g) Target signature
   h) Site statistics
   i) Perturbation
   j) Curve fitter
   k) Time averager
   l) Orientation
   m) Coordinate transformations
   n) Faraday rotation
   o) Stable satellite analysis
   p) Decoy generator
   q) Tumble simulator
   r) Point mass
   s) Amplitude orientation
   t) Wake length - $C_D A$

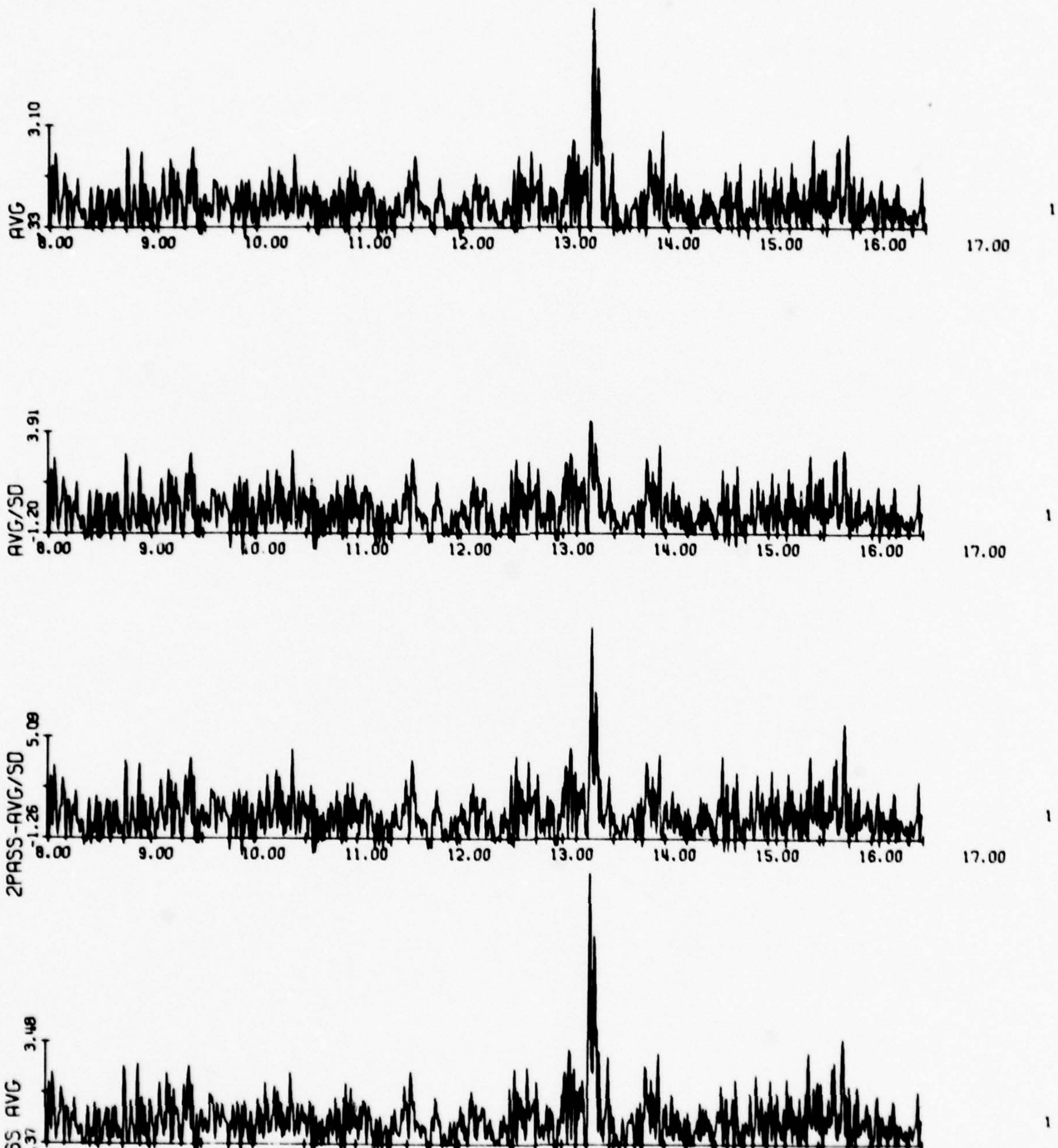


Figure II-3. Examples of Processed Data

I. OTHER PROGRAMS

1. BEAMFORMING

The Heavy Military Electronics Department has been actively engaged in the design of a beamformer for the C/PAS project. Studies in this area were initially performed on contract funds and now are being continued on internal funding.

The beamformer that has been designed is primarily digital. It utilizes both phase and delay for the beamforming and beam-steering functions. It compromises the desirable aspects of both the time-delay beamformer and the phase-steered beamformer. The major advantage of this beamformer results from the fact that the sampling rate is dictated by the signal bandwidth, not the highest frequency of the received signal (carrier plus signal bandwidth). This allows the sampling rate to be reduced significantly and reduces the signal storage requirements tremendously. In conjunction with this effort, extensive studies were made to determine the effects of signal amplitude quantization, phase and time-delay quantization, and digital frequency shifting. The beamformer has been evaluated for both the passive and active modes of operation and numerous patterns have been plotted to demonstrate its feasibility under all environmental conditions.

2. ARRAY AND TRANSDUCER DEVELOPMENT STUDIES

During the past few years, the Heavy Military Electronics Department has designed and built development models of transducers in conjunction with the C/PAS project. Numerous analytical tools have been developed, with the aid of the computer, to predict the performance of the array-transducer complex. Radiation patterns, forces, velocities, impedances and bending moments have been calculated, based on the mutual interaction of the elements of the array subject to a normal plus rocking motion. Motions of the individual elements and their relationship to the internal characteristics of the transducer elements and the driving transmitter units has also been taken into account.

SECTION III
BIOGRAPHIES

To accommodate for the possibly varied nature of the requested tasks, the resumes of several candidate personnel are presented in this Section. In addition, resumes of Mr. S. M. Garber and Dr. J. P. Costas are included, since they will be available in an advisory capacity to the assigned personnel. The extensive backgrounds of these Consultants will be utilized even though they are not assigned to the tasks.

<u>DR. J. P. COSTAS,</u> Consultant

BSEE, Purdue University, 1944
MSEE, Purdue University, 1947
ScD, Massachusetts Institute of Technology, 1961

Dr. Costas is presently a Consulting Engineer for Advance Technological Developments in the Advance Projects Development Section with the Heavy Military Electronics Department in Syracuse, New York. Since 1964, he has been concerned with the investigation of signal processing techniques for use in ASW Systems.

Formerly a Consulting Engineer for Engineering Analysis, Dr. Costas was involved in over-the-horizon radar techniques and investigation of propagation, antenna design, backscatter characteristics and associated signal processing requirements. Also, as a Consulting Engineer for Communications and Missile Guidance for five years, Dr. Costas was responsible for the direction of advanced project groups concerned with the development and application of synchronous techniques to a variety of communications problems.

Dr. Costas joined the Engineering Analysis Section of General Electric's Electronics Laboratory in 1951. He was responsible for analytical and experimental work involved in solving problems brought to the Laboratory by various operating Departments of the Electronics Division; areas of effort included color television, communications theory and systems, noise and coding techniques. He later transferred to the Communications Section of the Electronics Laboratory as a Consultant, and was appointed Manager of the Communications Section in 1955, where he was

responsible for both administrative and technical supervision of project groups involved with specialized problems in communications. Typical projects concerned underwater communications, noise modulation, secure communications, voice bandwidth reduction, single-sideband systems, multiplex systems, and synchronous techniques.

From 1944 to 1946, Dr. Costas was a radar officer in the U. S. Navy. After completing radar technology schools at Harvard and M. I. T., he was assigned to the electronic field service group at the Naval Research Laboratory. In this group, he was responsible for the installation and field service of a new type of radar fire control system delivered to the Fleet. He also prepared a course in radar for technicians, and trained operative and maintenance personnel.

Dr. Costas was a member of the teaching staff at Purdue University from 1943 to 1944 and from 1946 to 1947. He has also been a member of the teaching and research staff at M.I.T., where he taught courses in electrical measurements and network areas in statistical communication theory.

Dr. Costas is a Fellow of the IEEE; Senior Member, Research Society of America; and a Licensed Professional Engineer, State of New York. He was a consultant to the Assistant Secretary of Defense for Air Force long-range communication problems from 1956 to 1958.

He was awarded a patent for signal processing arrangement (2,868,981) and has patents filed for communications system (477,169) and, as co-inventor, for controllable signal transmission network (655,717). He has applied for patents for several other communications devices.

Dr. Costas' reports include: Periodic Sampling of Stationary Time Series, Technical Report No. 156, Research Laboratory of Electronics, Massachusetts Institute of Technology, May 16, 1950; Interference Filtering, Technical Report No. 185, Research Laboratory.

He has written the following articles: "Synchronous Detection of AM Signals", Proceedings of the National Electronics Conference, 1951, also published in Tele Tech (July 1952); "Coding with Linear Systems", Proceedings of the IRE 40, 1101-1103 (September 1952); "Synchronous Communications", Proceedings of the IRE 44, 1713-1718 (December 1956); "Phase-Shift Radio Teletype", Proceedings of the IRE 45, 16-20 (January 1957); "Discussion of the Single-Sideband Issue", Proceedings of the IRE 45, 534-537 (April 1957); "Transmitter Circuits for Suppressed-Carrier AM", Electronics, 128-131 (December 1, 1957); "Poisson, Shannon, and the Radio Amateur", Proceedings of the IRE 47, 2058-2068 (December 1959); "Linear Modulation Systems", Lecture presented at the Massachusetts Institute of Technology Summer Session on Modulation Theory and Systems, August 1960, and published in book form by M.I.T. with other papers; "Information Capacity of Fading Channels Under Conditions of Intense Interference", Proc. IEEE, Vol. 51, pp. 451-461; March 1963.

S. M. GARBER, Consultant

BSEE, Yale University, 1949
Graduate, General Electric Advanced Engineering Program, 1952

Mr. Garber is a consultant, signal processing, with the Heavy Military Electronics Department. Prior to his present assignment in Advanced Sonar Development, Mr. Garber was Manager of the Transducer and Techniques Development Engineering, responsible for design and development of sonar transducers, and for advanced sonar techniques programs. He has been engaged in sonar engineering since 1957 and has provided technical consultation on a number of systems such as the BQN-3 secure depth sounder, the SQS-26 shipboard sonar, the bottom doppler navigation equipment and underwater communication.

Before joining HMED, Mr. Garber was a consulting engineer with the Electronics Laboratory, where he served on a number of communication projects. Of particular interest among these are a secure radio-teletype communication system for the Navy (which grew out of the underwater communications work), an experimental study of display improvement techniques applied to mine hunting sonar, and a theoretical study of asynchronous multiplexed communication channels.

On other assignments with the Electronics Laboratory, which he joined in 1952, Mr. Garber was project engineer on a Company-supported secure underwater acoustic, submarine-to-submarine communication development program. This work was carried through actual sea testing of breadboard equipment aboard submarines. He was also project engineer for the feasibility study and development of systems for Polaris Command Communication.

Mr. Garber was a member of the Communication and Navigation Committee of Project NOBSKA in 1956, and a member of the ARTEMIS Data Processing Committee. He is presently a member of the IEEE and recently presented a technical paper on high resolution sonar signals in a multipath environment, published in the IEEE Transactions on Aerospace and Electronic Systems. He is also a member of the Acoustical Society of America.

W. S. ANDERSON, Engineer

BSEE, Notre Dame, 1949
MSEE, Harvard, 1951

Mr. Anderson has had 17 years of engineering experience in sonar and radar data reduction and analysis, radar equipment engineering and electric motor design. For the past two years, he has been working with analysis of sonar sea data on a computer-aided detection program. On a preceding assignment, he worked with data reduction and analysis of radar data covering experimental missile programs.

D. R. COLASANTI, Engineer

BSEE, Syracuse University, 1964

As an Advanced Sonar Development Engineer in the Heavy Military Electronics Department, Mr. Colasanti is presently involved with the digitizing equipment (A/D) and simulation work for the AN/BQR-7 DIMUS Simulation Study.

Since joining the Department in 1959, his experience has been principally in the digital computer area. He has programmed, in machine language and Fortran (I, II and IV), for the IBM 650, 704, 709 and 7094 computers. He has also programmed in machine language for the LPG-30, M-236 (real time, core and drum) and the

AN/UYK (real time). He is experienced with a variety of peripheral equipments such as card and paper tape punches and readers, Teletypewriters, Flexowriters, card sorters, and with various magnetic tape to card and plotter techniques (CRT, Behnson-Lehner, printer plot programs and CALCOMP). He has designed and developed computer programs for the Down Range Project (Eastern Test Range), a simulation program for the Over-the-Horizon Radar Study, and has been involved in maintenance and implementation of programs for two Air Force satellite detection sites and in programs for the Polaris Wake Study Analysis.

G. P. HAMMEL, Engineer

BSEE, Syracuse University, 1961
MSEE, Syracuse University, 1965

Mr. Hammel is an Advanced Sonar Development Engineer in the Heavy Military Electronics Department. He recently returned to General Electric after working for the past year at the Ordnance Research Laboratory of Penn State University. While at ORL, Mr. Hammel was the Project Engineer of a field data reduction and analysis program. He was responsible for the general purpose computer implementation of a digital matched filter detection system and the statistical analysis of target echoes of large time-bandwidth product signals. He also served as a consultant to the HRB Singer Co. in the digital processing area.

From 1961 to 1966, Mr. Hammel was involved in the development and application of digital techniques to sonar signal processing. He contributed to the development of the General Electric all-digital DIMUS passive sonar for the AN/BQR-2B. He coordinated the analytical studies for an all-digital tracking system for the AN/BQR-2B. In addition to conceptual work for the AN/BQR-7 DIMUS, he contributed to the active beamforming studies for the C/PASS.

In 1965, Mr. Hammel coordinated studies of digital filtering techniques and a study of the effects of hard-limiting. Mr. Hammel extended this work into a technical thesis "Some of the Effects of Amplitude Quantizing Gaussian Signals".

Mr. Hammel's professional career began in 1959 in GE's Specialty Devices Operation where he designed square BH loop magnetic circuitry.

He is a member of the IEEE, Tau Beta Pi, Pi Mu Epsilon, and Eta Kappa Nu societies.

R. L. LAVALLEE, Engineer

BSEE, University of Massachusetts, 1961
Graduate, General Electric Advanced Engineering Program (3 year course), 1964

Mr. Lavallee is an Advance Sonar Development engineer in the Heavy Military Electronics Department. He is presently involved with mathematical and laboratory analysis of sonar signal processing techniques related to the AN/SQS-26 Sonar System. These studies include coded pulse processing for various codes, and sea data analysis for comparing the detection performance of various waveforms and noting the effect of the medium on signal processing.

Mr. Lavallee joined the General Electric Company in 1961 on the Engineering and Science Training program. Work on this program consisted of assignments in various Departments within the Company. These assignments consisted of electronic and servo design and improvements related to the MK 80 and MK 84 fire control systems (Ordnance Department); improving process control on a high reliability transistor for the Minuteman missile (Semiconductor Products Department); design of a high-speed data transceiver (Military Communications Department); improving temperature stabilization techniques for gyroscopes (Instrument Department); and a guidance and navigation simulation for trans-lunar trajectories (Apollo Support Department).

Mr. Lavallee is a member of the IEEE, Tau Beta Pi, and Eta Kappa Nu. He recently presented a technical paper on correlation loss measurements of linear FM echoes at the 24th Navy Symposium on Underwater Acoustics. He is presently working toward an MSEE degree at Syracuse University in the field of signal processing.

R. L. MACKEY, Technician

Mr. Mackey joined the General Electric Company in 1956 after four years experience as a sonar maintainance man and operator in the U. S. Navy. He joined the Advanced Sonar Development group as an Engineering Assistant in 1965. His present duties include building, testing, and documenting advanced signal processing and display techniques. These jobs have included a Constant Variance amplifier, to maintain a constant false alarm rate over the entire range interval; an Adaptive Notch receiver, to pre-whiten returns by adapting a notch filter to match the spectrum of the returning reverberation; a comparison between a logarithmic amplifier and an AGC amplifier; and improved display techniques.

Prior to his present assignment, he was with the Heavy Military Electronics Department Field Programs Unit for one year and had eight years experience as a test man on systems, subsystems, and cabinet test on many major HMED radar and sonar systems.

C. A. SABATO, Engineer

BEE, New York University, 1959
25% Credits toward MEE

Mr. Sabato joined the General Electric Company in 1965 as an engineer in the Advance Sonar Development group of the Heavy Military Electronics Department. He is presently working on the design and development of an Adaptive Notch Filter for an active sonobuoy sonar system using integrated circuits. He recently completed the design and development of A/D and core memory input/output logic circuits for a sonar digital storage display. Previously, he was responsible for the design and development of the stabilization system for a 9-element planar array sonar beamformer and a logarithmic IF amplifier for the AN/SQS-26 Sonar.

Prior to joining General Electric he had eleven years experience as an engineer with the Sperry Gyroscope Company, where he was concerned with many large military systems. For the Talos Radar (AN/SPG-49) he was responsible for the design, development, and evaluation of the transistorized electronic counter-countermeasures (ECCM) subsystem and development of ECCM logic and operating doctrine for the Talos Weapon System (MK-77). He also designed and developed the transistorized Master Synchronizer (AN/SPA-42) as well as solid-state D/A, A/D, and core memory circuits in the Weapon Direction Equipment Computer for the Talos, Tartar, and Terrier missile fire control systems.

W. T. SMITH, Technician

Mr. Smith joined the General Electric Company in 1956 after four years experience as a sonar maintainance man and operator in the U. S. Navy. He is presently attached to the Advanced Sonar Development unit of the Heavy Military Electronics Department as a technical specialist. He is involved with the HMED analog-to-digital conversion facility interface with the GE 415 computer. He has also been responsible for the data acquisition and data reduction of the R/M test program on the AN/SQS-26 CX system.

Mr. Smith performed reduction and analysis of analog sea tapes taken aboard the U. S. S. Wilkinson for three years. He has built various analog and deltic correlators for active sonar systems, and has been involved in integration of the Velocity Integrated Coherent Indicator (VICI) with the AN/SQS-4 sonar system and also on Project "Fishbowl", a surveillance system.

D. W. WINFIELD, Engineer

BME, General Motors Institute, 1961
MSEE, University of Michigan, 1965

Mr. Winfield joined the General Electric Company in 1965 in the Advance Sonar Development group of the Heavy Military Electronics Department. He is presently performing a study of target detection on a multiple ping basis, the design of an algorithm to implement the detection process, and the development of a system model to evaluate the algorithm in a computer-aided detection study.

Mr. Winfield has recently been involved in the analysis of the acoustic channel time and frequency spreading from experimental sea data using the AN/SQS-26 Sonar, and the effect of the "medium" distortions on signal processing functions. He has also been involved in modeling the medium distortions with computer simulation programs and analyzing data spectrums in the frequency domain through use of Fast Fourier Transform Techniques to reduce computer analysis time.

Mr. Winfield's professional career started in 1956 while he was employed by the General Motors Corporation and attending the General Motors Institute as a co-op student. During this time, he designed and developed an electromechanical torque transducer system for electronic control of an automotive transmission. Subsequent to graduation in 1961, he designed instrumentation and analyzed magnetic circuit parameters in small DC motors for their effect on motor performance.

In 1963, while studying for his MSEE degree at the University of Michigan, Mr. Winfield joined the University of Michigan's Institute of Science and Technology. There, he was engaged in the study of procedures to obtain a secure communication channel for guidance and control of a space vehicle and analysis of the ECM, anti-multipath, and signal processing characteristics of a correlation type receiver for a special military LF hyperbolic navigation system.

Mr. Winfield is a member of the IEEE and the IEEE Professional Group on Information Theory. He recently presented a technical paper on the results of medium spreading measurements over the AN/SQS-26 Bottom Bounce path at the 24th Navy Symposium on Underwater Acoustics.

SECTION IV
AVAILABLE FACILITIES

This Section describes facilities available to the Heavy Military Electronics Department for direct support of the tasks outlined in RFQ N00140-68-Q-0120.

A. DIGITAL COMPUTERS

The primary HMED digital computer facility shown in Figure IV-1 consists of an IBM 7094 computer supported by the GE 415 general purpose computer to handle input/output functions. Thirteen digital tape drives are used in conjunction with the 7094 computer. A time-shared computer facility using the GE 265 TSS general purpose computer is also available to HMED through three teletype 35ASR terminals. Both of the aforementioned facilities are described in greater detail in the following sections.

1. DIGITAL TAPE DRIVES

Thirteen IBM 729 Mod 6 tape drives are available as support equipment for the IBM 7094 main computer facility, and four GE 304C digital tape drives are available in support of the GE 415 computer. The IBM 729 Mod 6 tape drives can read/write seven-track digital tape at 200/556/800 cpi (90 KHz). The GE digital tape drives are capable of read/write on seven-track digital tape at 200/556/800 cpi (30 KHz).

2. IBM 7094 COMPUTER FACILITY

The IBM 7094 facility and GE 415 computer at HMED have the following characteristics:

	7094-I (IBM)	415 (GE)
Memory	192,000 characters	64,000 characters
Cycle Time	2 microseconds	5.8 microseconds
Printer	150 lines per minute	2(1200) lines per minute
Card Reader	250 cards per minute	2 (900) cards per minute
Card Punch	No punch	300 cards per minute

Figure IV-1. Digital Computer Facility

(continued)	7094-I (IBM)	415 (GE)
Magnetic Tapes	13 at 200/556/800 char. per inch densities (90 KHz) on 2 channels	Four at 200/556/800 char. per inch densities (30 KHz) on a single channel
Perforated Tape	None	Read 500 char. per second Punch 150 char. per second

FUNCTIONS:

7094	Main-line problem solving (engineering problems, payroll, accounting, modeling, data processing storage and retrieval, numerical control for machine tools, etc.) and utility (sorts, tape dumps, tape copy and compare); very little peripheral-type operations.
415	Primarily concurrent media-conversion processing to support 7094; some utility processing (tape searches, dumps, copies, etc.); 1401 computer simulation; A-to-D conversion interface; very little main-line problem solving.

The primary digital computer facility is supported by software programs developed by the Department for copying digital tapes, additional formatting of data, editing of data or reformatting digitized data for entry and further processing by other digital equipment. The following are software programs for handling digitally formatted tapes developed for other related programs:

1) Digital tape copy, compare and dump, visual tape dump
2) Binary tape dump
3) Unpack Data
4) Edit Tape
5) Merge Tapes
6) Error analysis and unpack Tape.

Computer programs also exist for the statistical analysis of sonar data, which were written under other related programs. These software packages perform statisical analysis on experimental data such as computation of estimates of power density spectra of a time-limited waveform using fast Fourier transform methods.

Software programs are available for calculating rank statistics, density functions, distribution functions, and auto- and cross-correlation functions for time or ensemble records of experimental data. Computer programs have also been developed

with the capability of making a contour plot of data using the CALCOMP/760/ plotting system. Examples of work done by the CALCOMP are shown in Figures IV-2, -3, -4 and -5. Figure IV-3 shows the capability for making contour maps.

3. TIME-SHARING COMPUTER FACILITY

HMED has three teletype terminals (35ASR) connected on the time-sharing computer system to the GE 265 TSS general purpose computer facility in Schenectady. The time-sharing system will accept input data and programs directly from the teletype keyboard or from the paper tape input. The time-sharing computer facilitates computations of moderate complexity and provides problem solutions immediately, without the turn-around time required for batch processing. Data that is on magnetic tape can be converted to paper tape by use of the GE 415 facility, and inputed via the teletypwriter for analysis at a remote terminal via the time-shared computer. Programs and data, stored in disk files on the time-sharing system, can also be used by more than one remote terminal.

B. ANALOG/DIGITAL CONVERSION FACILITY

The Heavy Military Electronics Department has a fast turn-around A/D conversion facility capable of writing digital tapes at 800, 556, or 200 cpi. A functional block diagram of this facility is shown in Figure IV-6. The heart of the system is the GE 415 digital computer, with one tape drive and the typewriter as required peripherals in the operation. A REDCOR A/D converter, computer interface circuitry, general-purpose power supplies, and a seven-channel instrumentation analog recorder (VR3300) are also required for A/D conversion.

When in actual operation, the entire system is slaved to the A/D converter sample pulse input. For every sample pulse received, the A/D converter generates a 12-bit number representing the analog input level at sample time and this number is sent to core memory. When a prescribed number of samples have been taken, core memory is automatically read out onto the digital tape as a physical record. This process continues under system control until the user intervenes, either by opening the clock gate or via typewriter control. A completely asynchronous mode of operation is also provided. Sample pulses into the A/D converter a· 'uate the entire process so

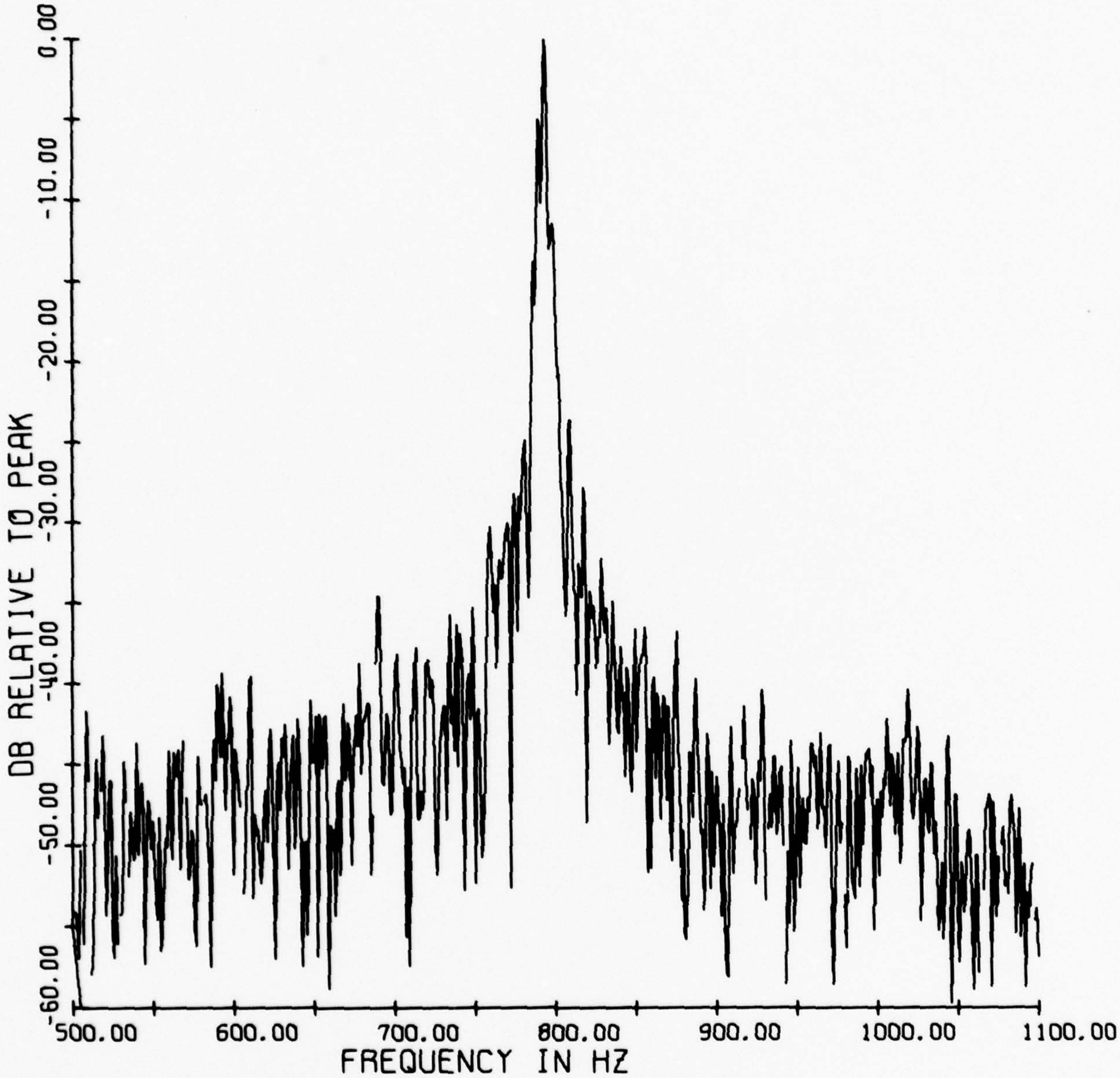


Figure IV-2. Estimated Power Spectral Density

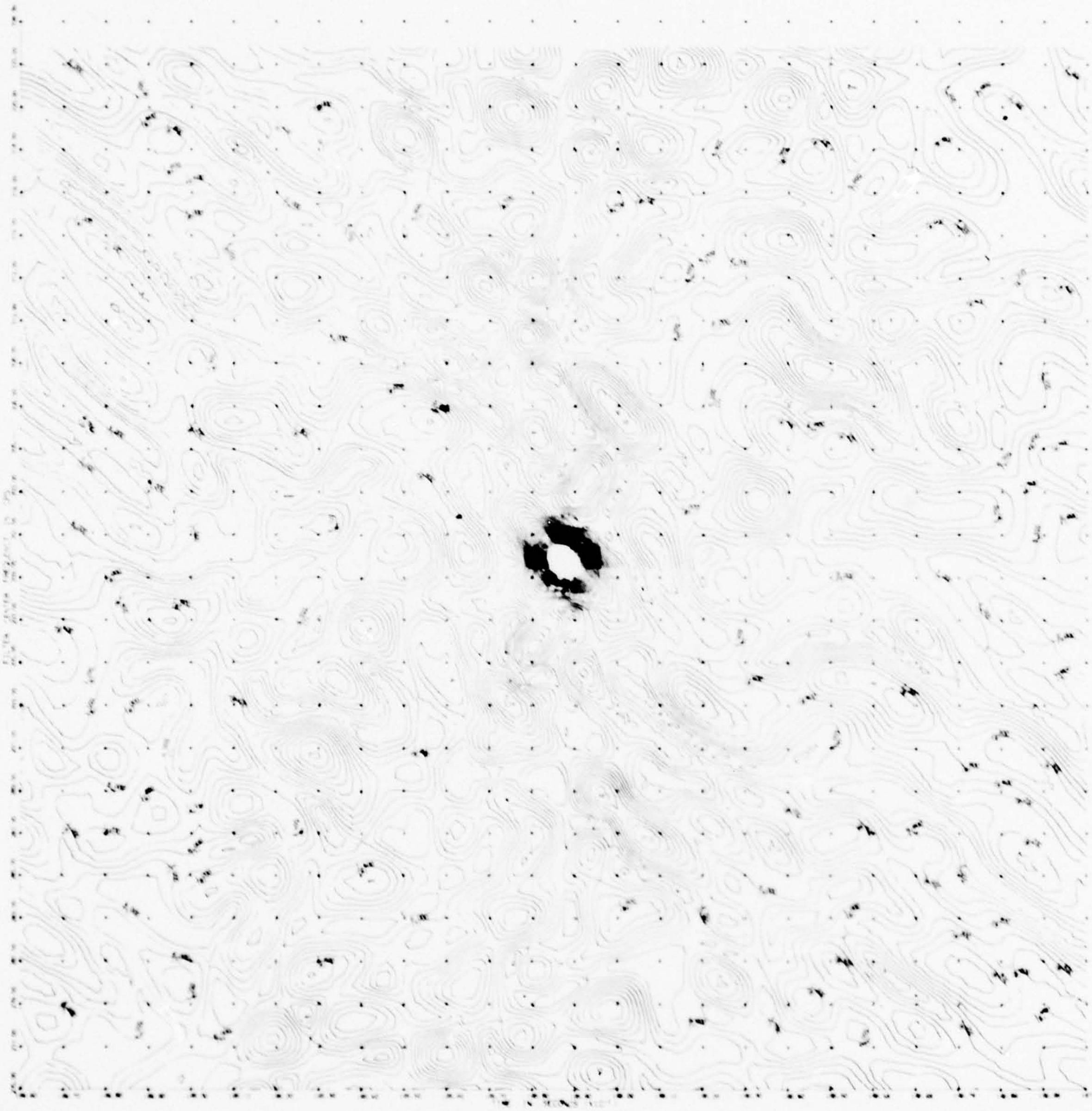


Figure IV-3. PRFM Contour Map

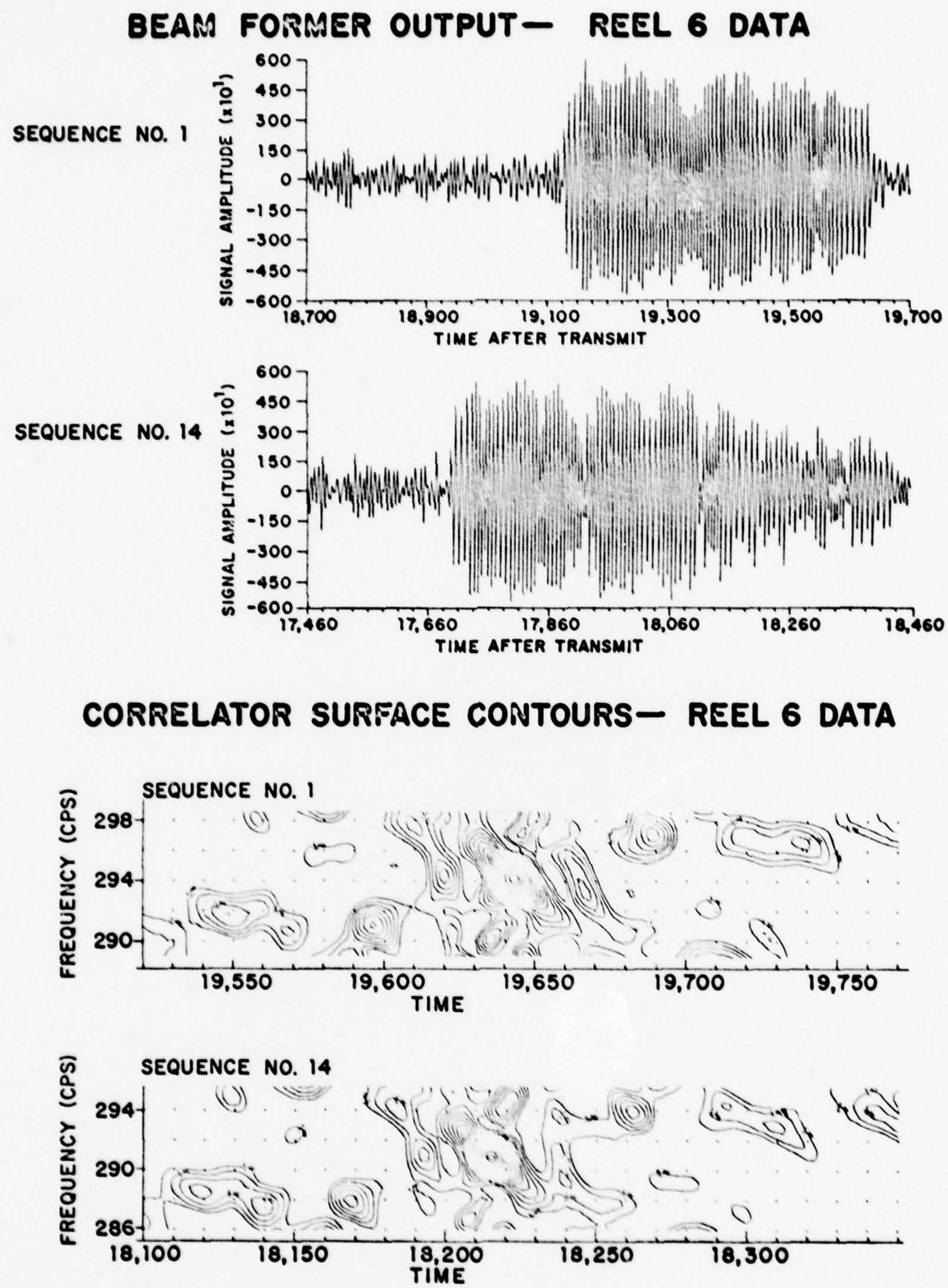


Figure IV-4. Raw Data and Signal Contour Maps

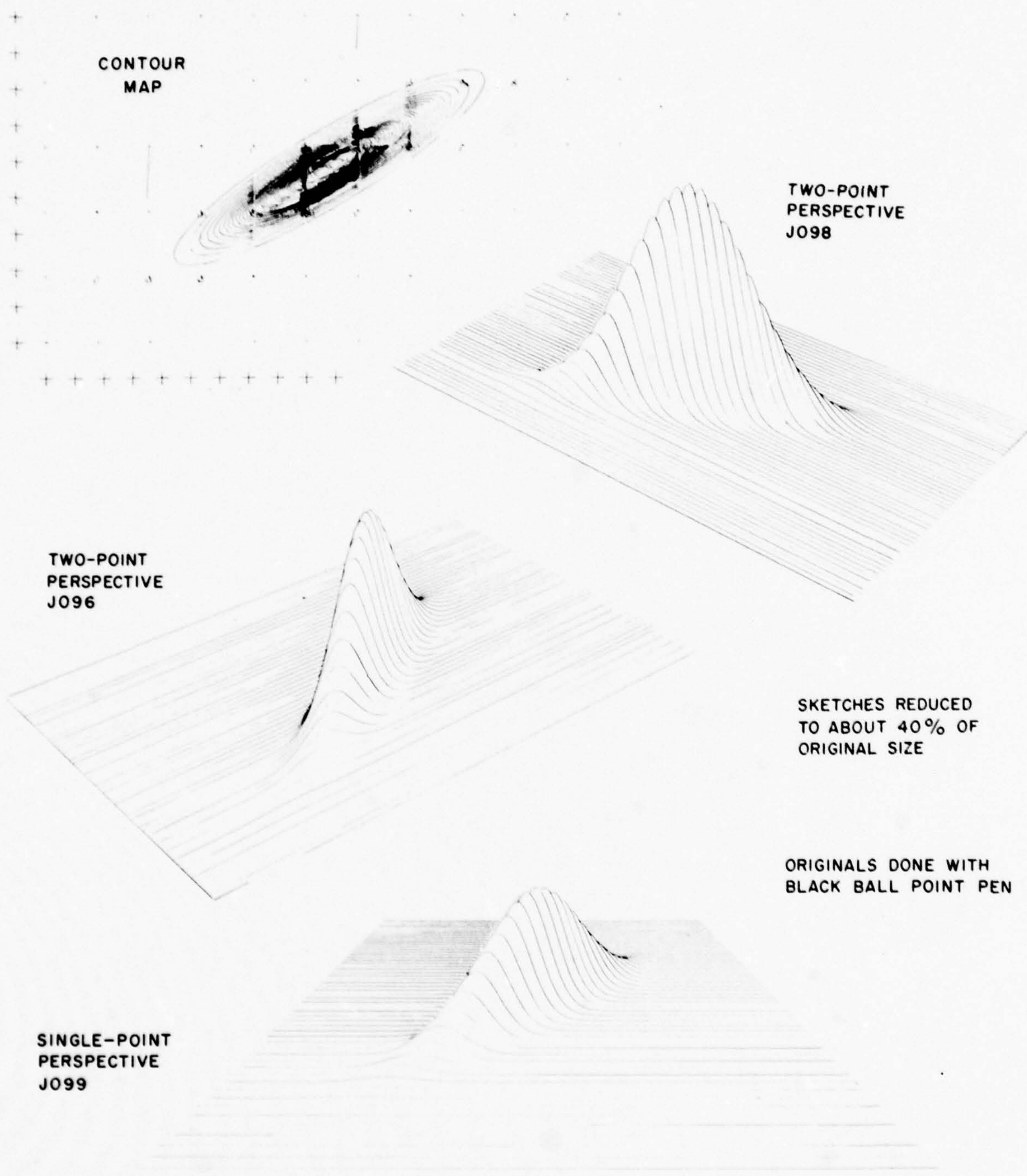
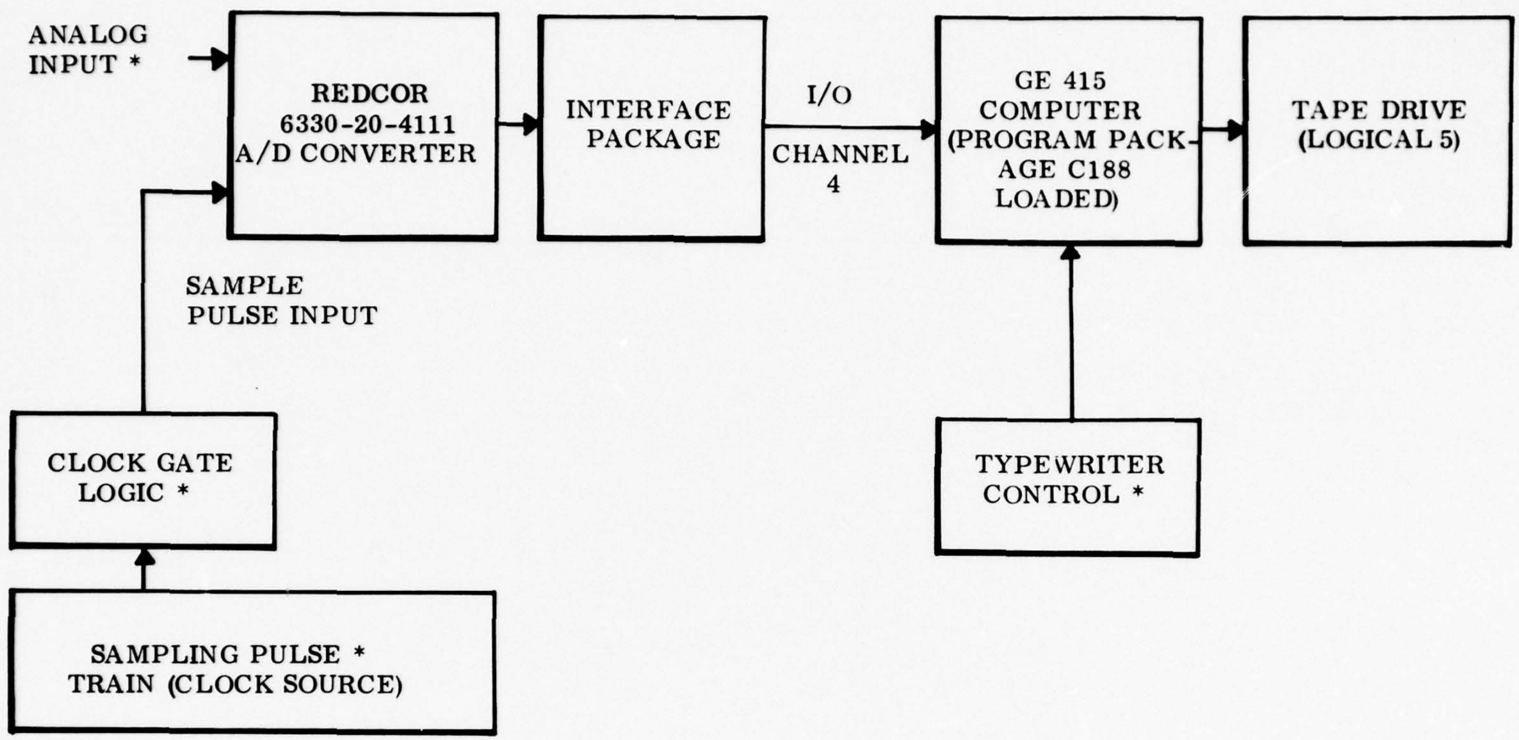
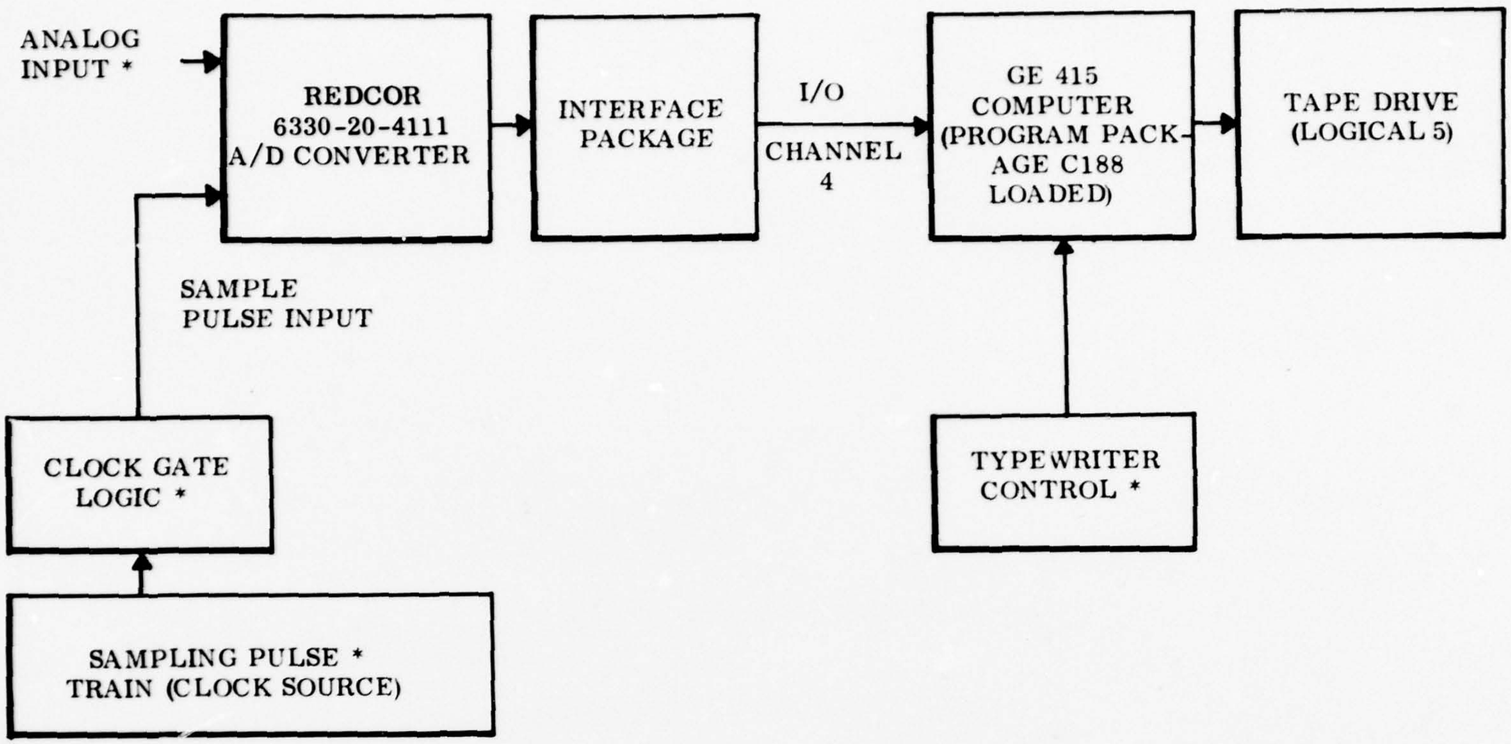


Figure IV-5. Prospective Plots of Contour Map



* USER SUPPLIED AND/OR CONTROLLED

Figure IV-6. Analog/Digital Conversion Facility, Block Diagram



* USER SUPPLIED AND/OR CONTROLLED

Figure IV-6. Analog/Digital Conversion Facility, Block Diagram

that almost any sampling format may be used. (There is an upper limit to the sampling rate.)

This asynchronous feature gives the user considerable flexibility in the design of the sampling logic for a particular job. In some cases, clock-pulse control may amount to little more than a pulse generator and a manually-operated switch. In other cases, sampling pulses and gating signals might be derived from analog tape channels and processed by extensive logic circuitry to produce the pulse-train output for A/D converter operation.

In almost all applications the conversion operation occurs in sequences with periods of A/D inactivity (pause) between sequences. During a pause, the user may make significant changes in operating format by use of typewriter control. Some idea of the versatility of this facility may be gained by a brief description of a few of the operating features:

1) End-of-file (EOF) mark(s) may be written at any point on the tape. When a file is closed, a message to that effect is printed, which contains the number of records in the file.

2) The physical record length may be changed as often and whenever desired. The user may select record lengths containing as few as 150 samples of data or as many as 5400 samples in increments of 150 samples.

3) Header records may be written at any point on the tape of any of the available lengths. Data for such header records is entered by the user in octal via the typewriter.

4) Status information may be obtained by the user via the typewriter at any time (pause or otherwise). The status message contains:

   a) The number of records already written in the file.

   b) The number of samples in memory buffers that have not yet been written on tape.

5) Recovery commands permit the deletion of any number of records in the current file or deletion of the entire current (open) file.

6) A file skip option on entry permits positioning of a partially written tape for further writing at a new session.

7) A number of error returns are incorporated, which inform the user of unusual situations that require his attention.

8) A hard copy record of the A/D conversion session is available from the typewriter for post-session reference.

The above description indicates the utility and flexibility of the system. As a further aid to the user, software packages that permit the binary tapes produced to be read directly from a FORTRAN source program are available.

The REDCOR A/D converter Model 663 can handle through-put rates of 45 KHz. The Analog/Digital Conversion Facility with the GE 415 computer will handle a continuous sampling rate of 10.4 KHz at 800 cpi. Table IV-1 shows a chart of maximum digitizing sampling rates for writing densities selected. It is important to note that an effective sampling rate in excess of 25 KHz can be obtained by recording data on the analog tape deck at a high speed and playing it back at a lower speed for the A/D conversion. Analog tape speeds of 1-7/8, 3-3/4, 7-1/2, 15 30, and 60 ips may be used for this process. Direct and FM recordings may be handled, and a maximum of 256 channels may be multiplexed for simultaneous sampling of an ensemble of analog input signals. Digital data is generally written in packed form, and record lengths of 150 samples to 5400 samples may be used. Unpacked data and other forms of formatting digital tape can be handled by software utility programs available at the digital computer facility and discussed in A2 of this Section.

TABLE IV-1

SUGGESTED MAXIMUM SAMPLING RATES (KHz)

Record Length	Writing density (cpi)			Record Length
(Sample Group)	200	556	800	(IBM 7094 Words)
1	2.0	3.0	3.3	50
2	2.6	4.7	5.4	100
3	2.9	5.7	6.9	150
4	3.0	6.4	8.0	200
6	3.2	7.4	9.4	300
8	3.3	7.9	10.4	400
10	3.4	8.3	↓	500
16	3.5	9.0	↓	800
20	↓	↓	↓	1000
28	↓	↓	↓	1400
36	↓	↓	↓	1800

C. GRAPHIC DIGITIZER

A Benson-Lehner (Model N-2) graphic digitizer is available at HMED to convert data from filmed records or hard copy into digital format. This instrumentation can be used for the analysis of data recorded as images or traces on transparent, translucent or opaque film or hard copy.

An Auto-Trol Model 3700/2D Graphic Digitizer is available to also convert hard copy into digital format. The 3700/2D console has five digits each in x and y, with a three-digit event counter.

Peripheral equipment used in conjunction with the 3700/2D are the Auto-Trol 3939 x - y Opti-Track, which provides a sealing area of 40" x 60" with selectable scale factors of 250, 500 and 1000 counts per inch, providing a repeatable measuring accuracy of ±0.001 on either axis and a selector attachment for readout onto IBM cards.

D. DIGITAL X-Y PLOTTER

A CALCOMP Model 760 X-Y plotter is available for use with the IBM 7094 computer facility. Several samples of CALCOMP generated output plots were shown in Figures IV-2 through -5. These plots illustrate the use of the CALCOMP and associated software packages for various data display formats. This facility allows the direct plotting of digital output in graphical form.

E. ANALOG TAPE DRIVES

HMED presently owns several CEC VR3300 magnetic tape recorders, one 14-channel recorder handling 1" tape and four 7-channel recorders handling 1/2" tape. With these five machines, 25 direct record and playback amplifiers and 22 FM record and playback amplifiers are available. Four precision power supplies are also available for use with the recorders. A tape loop adapter (Model 12-383-2) can be used with the 7-channel machines. The loop will handle up to 85 feet of tape and has been used extensively for simulations requiring repetitive analyses.

At the present time, a Government owned Sangamo 4711 magnetic tape recorder is at our facility and is being used on the AN/BQR-7 DIMUS simulation. The machine has a non-standard head stack to permit the recording of 56 channels on 2" magnetic tape. A full complement of direct record and reproduce electronics are available for 3-3/4 and 15 ips.

F. ANALOG COMPUTERS

The HMED analog computer facility consists of three equipments:

1) EA real time computer, including:

  a) Six-channel recorder
  b) Patchboard (7 available)
  c) Digital voltmeter
  d) 80 potentiometers
  e) Quarter square multipliers (3 available)
  f) Servo multipliers (6 available)
  g) Pot padder (5)
  h) Noise Generator (2)
  i) 40 amplifiers
  j) Resolvers (4)
  k) D.F.G. and pot padder control panel
  l) Three electronic multipliers
  m) X-Y plotter
  n) Diode function generators (3)
  o) ± volt reference supplies
  p) Low frequency oscillator (H.P. Model 202A)
  q) Control panel
  r) 20 integrator and summing amplifiers

2) GPS compressed time computer, including:

  a) Oscilloscope display and master control generator
  b) Berkley counter
  c) Four function generator summing amplifiers
  d) Two diode function generators
  e) Four function generator summing amplifiers
  f) Two diode function generators
  g) 24 potentiometers (96 available)
  h) 24 integrators
  i) Electronic multiplier (9 available)
  j) 24 amplifiers
  k) ±15 VDC reference supplies
  l) Second order lag
  m) 14 tie points to adjacent "PACE" computer
  n) Sine cosine unit
  o) Limiter
  p) Five electronic relays (transistorized)
  q) Electronic relay
  r) Switch panel repetitive/reset/real
  s) Two noise generators
  t) Power supply
  u) Sample and hold (four variables)
  v) Probability distribution analyzer

3) GPS real time/repetitive analog computer (recently acquired).

This combination of equipment makes a total of 250 amplifiers and associated non-linear equipment available to the system engineer for simulation. Figure IV-7 shows the GPS real time/repetitive operation computer, which has a useful frequency band from 0 to 100 KHz.

A cumulative distribution analyzer developed by HMED's Analog Computer Laboratory allows an operator to make statistical measurements as easily as he would make voltage measurements with a voltmeter. The output is in the form of ten decimal displays on the face of the instrument; each of these displays represents the number of samples of the input exceeding the threshold associated with its display. The instrument can accomodate any ensemble size, selected by the operator, from 1 to 1,000.

Selection of the samples is made in one of two possible ways at the discretion of the operator:

1) The samples can be taken at a pre-set time after the start of repetitive analog computer runs.

2) The samples can be taken when a control input goes through zero. The sampling rate can be as high as 20 KHz, so it can be seen that it does not take long to measure a "statistic".

An additional feature of the machine is that it can measure joint probabilities of two variables.

G. ANALOG SPECTRAL ANALYSIS EQUIPMENT

1. SPECTRAL ANALYSIS FACILITY

Analog filters are available to HMED from several components within the Department as well as at the Company's Research and Development Center at Schenectady. The Research and Development Center facility, described in the Appendix, is particularly suited for analog spectrum analysis on experimental data. The instrumentation performs spectral analysis in real time and records results on photographic strip film. The range of frequencies to be analyzed can be shifted by changing the frequency of the oscillator used to heterodyne the input to the intermediate frequency range of the filter. Effective filter bandwidths can be changed by playing tape recordings of signals at higher or lower speeds than the original recording condition. This facility has the capability of obtaining nominal effective bandwidths of 0.625, 1.25, 5, 10, 32, 64, and 128 Hz over the frequency range of 2 Hz to 100 KHz.

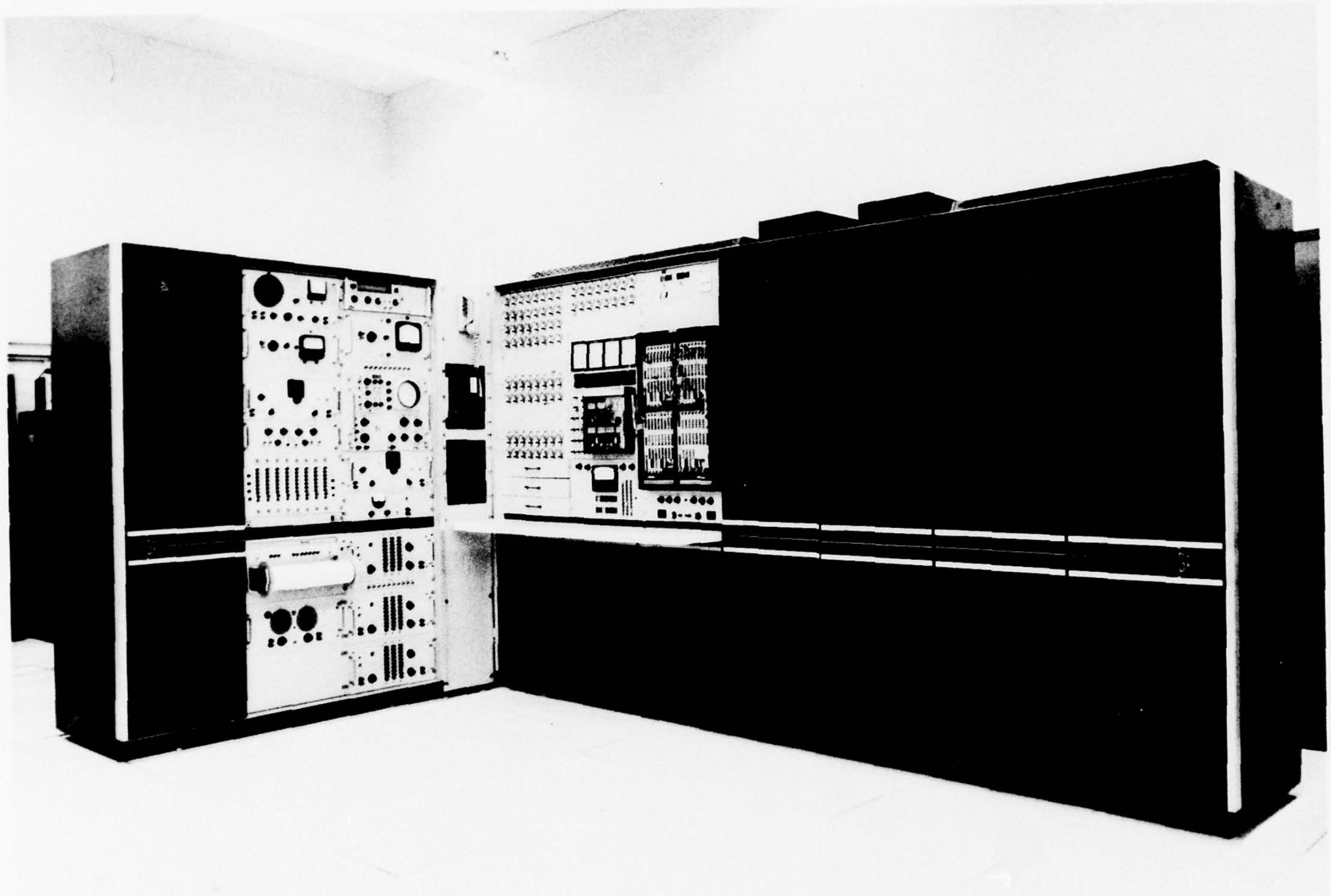


Figure IV-7. GPS Real Time/Repetitive Operation Analog Computer

2. ANALOG COMPUTER FILTER SYNTHESIS

Filters can be synthesized on the analog computer using operational amplifiers as building blocks for the filters. Filters can also be constructed with bandwidths of 1 Hz and having a frequency range from 1 Hz to several KHz.

3. WAVE ANALYZERS

Wave analyzers consist of a General Radio Type 1910-A and several Hewlett Packard 302-A and 310-A.

The General Radio 1910-A Recording Wave Analyzer consists of a 1900-A Wave Analyzer and the 1521 Graphic Level Recorder. The 1900-A has a range from 20 Hz to 54 KHz and selectable bandwidths of 3, 10, and 50 Hz. Incorporating excellent selectivity, this analyzer is especially useful for the separation and measurement of the individual components of periodic complex waveforms, such as harmonic and intermodulation distortion. It is particularly well suited for the analysis of noise, because its bandwidth in Hz is independent of the center frequency. The 1521 Graphic Level Recorder produces a permanent ink record of the level of the AC voltages in decibels. The trace may be plotted as a function of time. When used with the 1910 it can be used to automatically produce plots of level vs. frequency.

The H.P. 302-A has a frequency range from 20 Hz to 50 KHz with a 7-Hz bandwidth.

The H.P. 310-A has three frequency ranges: one from 1 KHz to 1.5 MHz with a 200-Hz bandwidth, another from 5 KHz to 1.5 MHz with a 1-KHz bandwidth, and a third from 10 KHz to 1.5 MHz with a 3-KHz bandwidth.

H. FLEXOWRITER

HMED has available three Frieden Model SPS Flexowriters for formatting of typewritten information. A Mohawk Data Science Model 1101 keypunch is also available for direct entry of data from keyboard to magnetic tape for input to the 7094 computer.

I. LABORATORIES

As a result of the work performed on the AN/SQS-26 active sonar system, an operational laboratory breadboard signal processor is now available for experimental and sea data tape analysis. Two CEC VR3300 (7- and 14-channel) tape recorders and 1/4" Ampex PR-10, along with the appropriate wow and flutter compensation circuitry, have been implemented for the laboratory analysis of sea tapes. For the processing of coded pulse data, the laboratory sonar breadboards include a DELTIC (clipper) correlator, a TIMAC (delta modulation) correlator and a VICI (Velocity Indicating Coherent Integrator) used for range-velocity displays. An AGC amplifier, constant-variance amplifier, logarithmic amplifier, and an adaptive notch filter have been used in the processing of pulsed CW data.

Also available for laboratory use are a Sanborn 6-channel recording system, Model 7706A. The system is complemented by four low gain DC preamplifiers (8801A) and two medium gain DC preamplifiers (8802A). A Honeywell Model 1508 Visicorder oscillograph has been used extensively in the laboratory. This Visicorder is driven from a 6-channel galvanometer amplifier Model T6GA. Galvanometers are available that permit a frequency response from DC to 5 KHz.

An extensive sea data tape library of active AN/SQS-26 sonar data, including various pulse codes with a variety of bandwidth-time products and several CW pulse lengths, are available for a spectrum of operational conditions. Most of the above experiments were planned and collected by General Electric personnel.

The laboratory facility also provides for the editing and preparation of sea data for A/D conversion. The prepared data is A/D converted and formatted on digital tapes to be compatible with the IBM 7094.

A core memory display to present active sonar data to an operator has been built on Company funds. Stored in a non-volatile magnetic core memory are 32,768 sonar measurements, each capable of sixteen different levels of amplitude. The stored information from memory is used to refresh a 17" cathode ray oscilloscope at approximately 46 times per second. Information is obtained from a multibeam active sonar system by multiplexing into an A/D converter. The digitized data is then stored in the same memory address format as used for the display.

J. UNDERWATER ACOUSTIC FACILITIES

Every facility required for underwater acoustic systems development is located within HMED in Syracuse, New York.

1. SONAR TEST FACILITY (R. V. COOLIDGE)

Among the General Electric sonar laboratory and test facilities is the sonar test ship R. V. Coolidge, a converted LCU 115 feet long with a 33-foot beam. This ship is capable of testing, static or underway, both large and small sonar equipments. Fully equipped with test instruments and power sources, it is being operated in central New York on Cayuga Lake. Figure IV-8 is a photograph of the ship and Figure IV-9 is a cutaway view.

The following is specific data on the R. V. Coolidge:

Location	Cayuga Lake
Depth at Facility	250 feet (maximum in area - 450 feet)
Length of Ship	115 feet
Beam	33 feet
Enclosed Deck Area	Length, 72 feet; Width, 28 feet, High Bay, 26 feet
Propulsion	Three 6M671 Diesels
Power	75-KVA underwater cable
Inside Well	18 feet square
Hoist Capability	10 tons normal
Maximum Mounting Capability	30 tons
Power Amplifier	20 kw-cw; 200 Hz-20 KHz; 37 kw pulse

This vessel is staffed with experienced transducer testing personnel and is under the direct supervision of the Transducer Development Engineering Unit of the Heavy Military Electronics Department. In addition to the unique mechanical features and the special transmitter listed above, a complete set of laboratory and special test equipment is permanently installed aboard.

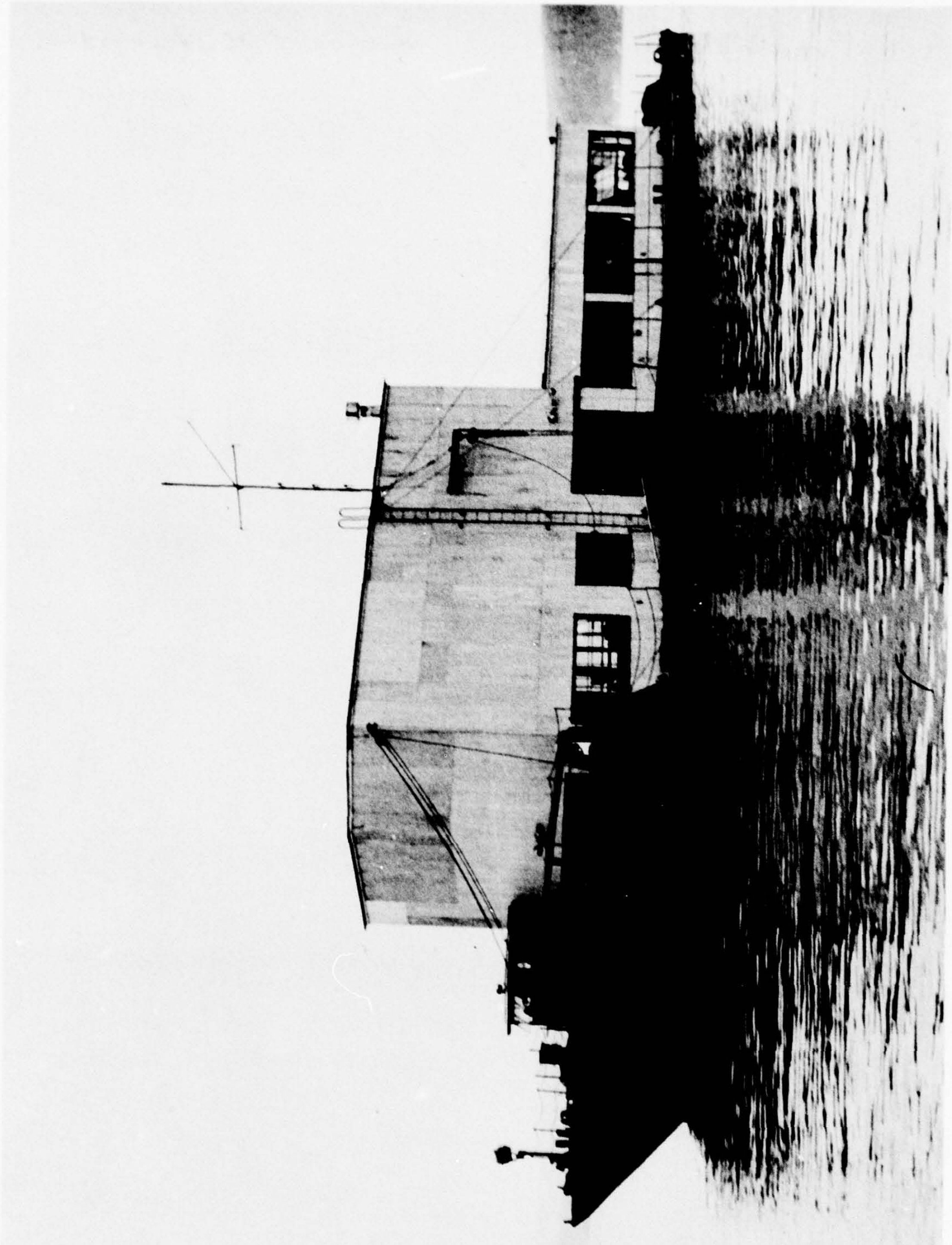


Figure IV-8. Sonar Test Ship, R. V. Coolidge

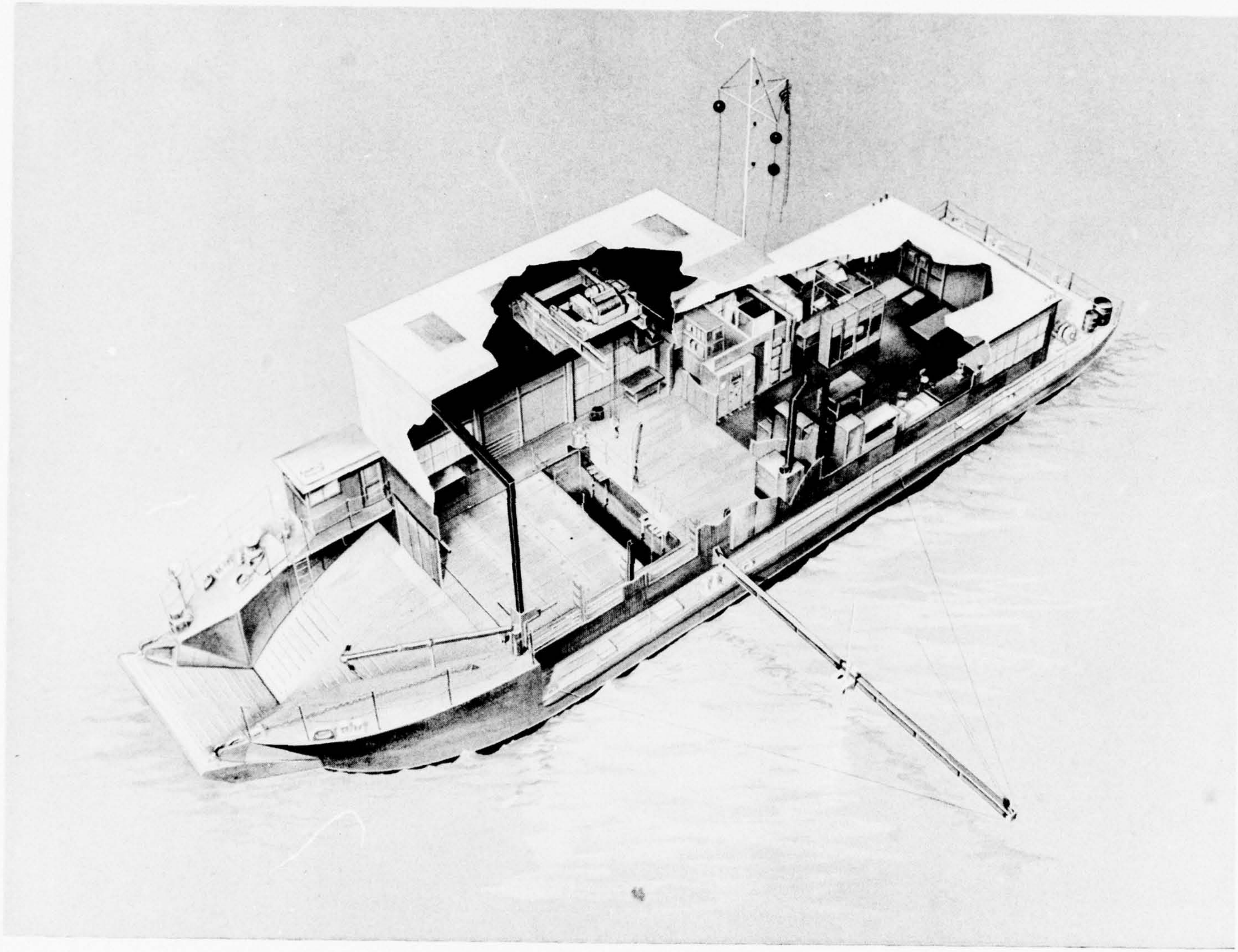


Figure IV-9. Sonar Test Ship, R. V. Coolidge, Cutaway View

A mechanical, variable-depth transducer positioning device is provided with leads for connection of a Scientific Atlantic Recorder for automatic recording of polar or rectangular positioning data and for recording transmitting-receiving response on transducers being tested. In conjunction with this recorder, either an HP302A (20 Hz to 50 KHz) or an HP310A (1 KHz to 1.5 MHz) wave analyzer is used as a source and as a tracking amplifier. The usual precision peripheral equipment is on hand for easy connection as required for the transducer being tested. This includes numerous recorders, amplifiers, oscilloscopes, oscillators, filters, counters, power supplies, pulse equipments, sweep drives, etc. Nine standard hydrophones operating from 10 Hz to 3000 KHz are included in the equipment on this vessel and are used for absolute measurements. Reciprocity calibration is performed at least once a month on these units. The wide-band transmitter operates between 200 Hz and 20 KHz and provides up to 37-kw pulse power output and 20-Kw CW. Units requiring larger amounts of power have been supplied by cable from shore connected to a 600-Kw trailer-mounted transmitter. A low power transmitter is also available for frequencies up to 1.5 MHz.

With the present facilities, transducers can be lowered to depth and oriented to point in any desired direction. Experimental data can be analyzed on the R. V. Coolidge and also recorded for further analysis at a later date. Two CEC VR3300 tape recorders with a frequency response up to 200 KHz are available for this purpose.

The following is a partial list of hydrophones available for experimental effort:

	TPZ 10 (CHESAPEAKE)	E 8 (GFE)	OTHER GE HIGH Q TRANSDUCERS
	Receive Only	Transmit & Receive	Transmit & Receive
Beamwidth	Omni-Directional	$\sim 10^{\circ}$	Very Directive
Sensitivity	-115 db	-125 db	Depends on specific transducer
Operating Band	1 KHz to 150 KHz	120 KHz to 1 MHz	Assortment of Center Frequencies from (60 to 120 KHz) and (300 to 400 KHz)

2. SONAR PRESSURE TEST TANKS

To calibrate deep-water, low-frequency transducers and to determine their ability to withstand high ambient pressures, the following pressure tanks are available:

1) 3,000 psi (4 feet diameter, 3-1/2 feet deep) - a new pressure test tank for testing transducers of larger size. Testing ascertains whether the transducers can withstand pressures to which they will be subjected under actual operating conditions.

2) 10,000 psi (12 inches diameter by 48 inches deep) - a high-pressure test facility for the testing of electronic components and subassemblies that are to be used at extreme depths without protective housings.

3) 20,000 psi (15 inches diameter by 40 inches deep) - mechanical pressure test facility for the testing of electronic component and subassemblies that are to be used at extreme depths without protective housings.

3. INDOOR TEST POOLS

Two indoor test pools are used for year-round pulse testing of transducers. The newer and largest pool at the Farrell Road Plant measures 30-feet square by 9-feet deep, and the other at the Court Street Plant measures 26 feet in diameter by 8-feet deep. Both facilities are complete with automatic radiation field plotting equipment, calibrated transducers which are used as secondary standards, high-power linear amplifiers, and impedance and sensitivity measuring equipment. In addition, the Farrell Road Plant test pool is equipped with 50 separate power amplifiers and phase shifters for driving individual transducers for conducting multi-element array studies.

4. SONAR TRANSDUCERS

Located in Underwater Acoustics Systems Engineering is a special transducer laboratory for the construction, testing and evaluation of prototype and model transducers. Models are used extensively in the design and development of extremely large transducers.

For many years, the General Electric Company has been active in the field of underwater acoustics and in the specific area of sonar transducers. General Electric has pioneered in the development of transducer materials, techniques and processes. Barium Titanate, available in quantity, is an economical and highly efficient acoustic

transducer material pioneered by General Electric. It has been used in transducer construction by the Company for well over ten years. In addition, newer materials such as lead titanate-lead zirconate, lead metaniobate and potassium sodium niobate have been employed as transducer materials. The excellent performance and reliability in the field of hundreds of these transducers attests to the practicality of assembly line production which has evolved from techniques and processes which were developed at General Electric.

Every phase of transducer development, from basic research of material to shipment of completed units to the Navy, can be performed within the Company. Basic reserach on new materials is carried out at the Research Laboratory at Schenectady, New York and at the Electronics Laboratory in Syracuse, New York. The development of new materials and improvement of existing materials is carried out by groups in the Electronics Laboratory and the Electronic Ceramics Operation in Syracuse, New York. The Electronics Ceramics Operation also carried out the manufacture of ceramic materials.

SECTION V
BIBLIOGRAPHY

The following bibliography is intended to document the overall competence of the General Electric Company in the fields of sonar signal processing and data analysis:

1) "Statistical Distribution Analyzer", T. Kohler and H. Hildebrandt (August 1963)

HMED's Analog Computer Laboratory has developed a Cumulative Distribution Analyzer that allows the operator to make statistical measurements as easily as he would make voltage measurements with a voltmeter. The output is in the form of ten decimal displays on the face of the instrument; each display represents the number of samples of the input that exceed the threshold associated with the display. The instrument can accommodate any ensemble size, selected by the operator, from 1 to 1,000.

2) "New Display Format and a Flexible-Time Integrator for Spectral-Analysis Instrumentation", D.E. Wood (January 1964)

This analyzer operates in real time by very rapid scanning of the outputs of a bank of bandpass filters. A unique process of true interpolation generates continuous spectral cross-sections that preserve accurate frequency relations of signal components. The cross-sections are recorded on strip film by photographing their display on a CR tube. A new display technique clarifies frequency patterns by marking just at the amplitude maxima or "peaks" in spectral crosss sections. A novel analog integrator now provides flexible time-averaging by adding spectral cross-sections in numbers variable from 2 to over 1000. The periods of averaging can be overlapped and the integrator could be equipped to provide simultaneous multiple outputs representing different averaging periods. The analyzer system is organized to take full advantage of the various kinds of flexibility with a minimum of operational steps. The combination of simple control, real-time operation, and strip-film recording provide the capabilities for large-scale investigations, while flexibility of analysis and display increases the information to be seen in the spectrographic pictures.

3) "Broadband Sonar Waveforms," L. W. Bauer (January 1964)

This report is an analysis of the performance of a sonar system using different types of "broadband" waveforms.

4) "Computer Simulation Study of the AN/SQS-26(XN-2) Sonar System," Dr. J. P. Costas, (May 1964)

Sonar input signals and noise were synthesized, as were various signal processor lineups, including the processors of the sonar system under investigation. Results were thus obtained for different processors under known and controlled input conditions.

5) "Increase Post-Detection Integration to Enhance Extended Targets," J. R. Pratt, (June 1964)

This memo describes a brief test that was conducted as a preliminary evaluation of the use of longer post-detection time constants for the correlator output of the AN/SQS-26 system. The object was to enhance extended targets such as bow aspect submarines, which give multiple peaks at the correlator output, and to evaluate the degradation for beam aspect targets, which give single peaks at the correlator output.

6) "Detection of Zero Doppler FM and CW Sonar Echos in Reverberation," S. M. Garber, (July 1964)

A comparative analysis is made of detectability of CW and FM sonar echoes under reverberation limited conditions. It is shown that an FM pulse with heterodyne correlation detection is equivalent to a short CW pulse having the same bandwidth.

7) "Laboratory Simulation of Coded Pulse Processing System for AN/SQS-26 (XN-2)," J. R. Pratt (July 1964)

This report describes the use of a laboratory breadboard of the AN/SQS-26 (XN-2) coded pulse signal processing system to evaluate the processing system and attempt to uncover areas where improvements in detection performance might be made.

8) "Computer Analysis of Sonar System AN/SQS-26 (XN-2) Sea Data," Dr. J. P. Costas and L. W. Bauer (October 1964)

Sea data recorded on the AN/SQS-26 have been converted to digital form and recorded on tapes that can be read directly by the IBM 7094 computer. Computer programs were written to simulate various signal processor systems, and selected returns were investigated in depth. The main intent of such processing is the determination of the environmental effects on received signals.

9) "Some Notes on Sonar System AN/SQS-26 (XN-2) Sea Data," Dr. J. P. Costas (May 1965)

Extensive computer processing of sea data returns has consistently revealed serious performance anomalies when particular modulation types are employed. The results obtained indicate that many of the anomalies observed in the processing of sea returns may be explained in terms of certain environmental or medium effects.

10) "Comparison of Processor Performance for the Detection of Decorrelated Pulse Trains," L. W. Bauer (May 1965)

Monte Carlo simulation techniques have been used to study the detection of pulse trains subjected to correlated, pulse-to-pulse fading. Although phased in terms of a radar detection problem, the results would be applicable to any multi-channel diversity system that combines equally-weighted pulses and uses threshold detection.

11) "Effect of Sampling Rate and Smoothing on Output S/N Ratios for Analog and Deltic Correlators," R. L. Lavallee (June 1965)

12) "Signal-to-Reverberation Characteristics of Various Pulse Codes for the AN/SQS-26 Sonar System," S. M. Garber (June 1965)

Several types of active sonar pulse waveforms are investigated to compare their performance under reverberation limited conditions.

13) "Constant Variance AGC & Time Constant Effects for the AN/SQS-26 Preformed Beam," J. H. Donegan and W. B. Dowell (July 1965)

The first problem deals with determining the optimum AGC time constants and the use of nonlinear discharge circuits. The objective is to "match" the AGC characteristics to the nature of the sonar background. The second problem concerns the reduced variance in background level for noise limited regions as observed on the PPI. The solution here was the development of a "constant variance" AGC technique.

14) "AN/BQR-7 All-Digital Performed Beam Receiver Study" -- Final Report", Volumes I and II (September 1965)

This report is primarily a design study to determine the deasibility of applying DIMUS Beamforming techniques to perform the passive detection function, using the BQR-7 hydrophone array. The study covers various general approaches to beamforming this type of array and concludes with a moderately detailed design of one mechanization. The final design was selected as optimum, based on reliability, and performance while using current state of the art components.

15) "Analysis of Detection Performance of an IF Correlator with Broadband Noise and Narrowband Signal Inputs" (U. S. Navy Journal of Underwater Acoustics), W. A. Adams and M. L. Fuller (October 1965)

Since the IF correlator has operational features that are useful in a passive sonar receiver, it is of interest to compare its detection performance with the two standard references, viz.; coherent and incoherent detector-integrator schemes.

16) "Automatic Target Following Function for Serial DIMUS-II --- Report" (November 1965)

The report objective was to provide an ATF mode compatible with the Serial DIMUS detection system, which enjoyed all the advantages of stable digital hardware.

17) "Medium Constraints on Sonar Design and Performance", Dr. J. P. Costas (November 1965)

The operating environment of sonar systems involves many complex mechanisms that produce both additive disturbances and distortions of the signal. If such environmental effects are considered to be properties of an effective sonar medium, it can be shown that the medium becomes a significant and irremovable part of any sonar system.

Design procedures that take proper account of medium effects are described; mathematical aids for use in good sonar system design are developed and demonstrated.

18) "Response of Correlation Receivers to Distorted Signals", S. M. Garber (November 1965)

Results of an analysis of the effects of range and doppler spreading of received echoes on the output of a correlation receiver.

19) "A Medium Oriented Approach to Sonar Signal Processing Design", Dr. J. P. Costas (January 1966)

The significant medium parameters are estimated from sea data analysis, and a selection of appropriate waveforms and signal processors is made. The resulting proposed system -- MEDIOR (MEDIum Oriented sonaR) -- is described.

20) "Initial Study of Noise Intervals of Sonar Returns", Dr. S. S. Shapiro (March 1966)

This report summarizes the initial efforts and results obtained from the study of the correlator amplitudes, from essentially target-free portions of sonar returns from surface duct and bottom bounce transmissions.

21) "Reverberation Spectral Spreading Due to Ship Motion, C/PAS", S. M. Garber (April 1966)

A function is defined, called the reverberation doppler density function (RDD), which describes the distribution of doppler frequency shift of reverberation in an active sonar system due to the effect of ship motion.

22) "A Relationship Between Time and Frequency Spreading in a Bottom Bounce Sonar Propagation Path", J. A. Edward (April 1966)

Time and frequency spreading due to the multipath structure of the medium are becoming recognized as fundamental limitations on the processing gains that can be achieved through coherent processing in bottom bounce sonar systems. In this memo, relationships will be presented showing the relative dependence of both types of spreading on a specific multipath structure.

23) "A Multiplexed Logarithmic Amplifier for Sonar Gain Control", J. H. Donegan and E. Chadwick (June 1966)

This report covers an investigation made into the use of a time-multiplexed logarithmic amplifier to provide a gain normalization function for many independent channels. The technique is based on the principle that a logarithmic amplifier with detection and differentiation can produce a constant output level independent of input level.

24) "The Effect of Systems Constraints and Environmental Distortions on Choosing Signals for Detecting Submarines", S. M. Garber (June 1966)

The performance capabilities of two basic sonar signals (a simple tone pulse and linearly frequency modulated pulse) are examined under conditions of varying relative levels of reverberation and noise, a multi-path environment introducing both range and doppler spreading of the signal, and where the doppler of the echo is known only within a wide range.

25) General Electric Seminar on Sonar Processing in Underwater Acoustics (June 1966)

The following papers were presented at a General Electric Seminar on Sonar Signal Processing in Underwater Acoustics held June 14 and 15, 1966:

"The Estimation of Periodic Signals in Noise", Drs. T. G. Kincaid and H. Scudder

"A Spatial Matched Filter for the Detection of Plane Wave Signals in an Arbitrary Noise Field", J. A. Edward

"Phase vs Time-Delay Steering for Linear Arrays and Broadband Signals", W. B. Adams

"The Reverberation Problem in Acoustic Homing Torpedoes", C. E. Thomas

"Time Bandwidth Problems Peculiar to Sonar Signal Processing", R. deBuda and S. Chow

"An Apparatus for the Display of Ambiguity Functions", C. Jagger

"Choosing Signals for Detection of Submarines", S. M. Garber

"Signal-to-Interference Performance of Amplitude Shaded Pulses Considering Sonar Medium Effects", J. Reddeck

"Computer-Aided Detection - Sonar Data Study", J. M. Jackson

"Radiation Theory for Planar Array Sonar", Dr. A. J. Martenson

"Wideband DIMUS", H. Hadley

"Non-Linear Filter", F. Schlereth

"Acoustic to Visible Image Conversion by Means of Holograms", L. Somers

"Experimental Passive Results", C. Stutt and D. E. Wood

"Techniques for the Optimization of Passive Sonar Performance", H. Crook and T. B. Lynch

"Beam Broadening for the SQS-26", Dr. R. J. Talham

"Signal Distortion in Bottom Bounce Transmission Due to Medium Effects", D. W. Winfield

"The Effect of Bandwidth-Time Products for Coded Pulse Transmission on the Observed Processing Gain for an Analog Correlator (Sea Data)", R. L. Lavallee

"An Adaptive Notch Filter Technique for Reverberation Limited CW Targets", J. H. Donegan

"Coherent Optical Processing Applied to Sonar", D. Duffy

"Digital Techniques in Passive Sonar", J. P. Nardello

26) "TIMAC - Time Compression Analog Correlator", L. W. Bauer (July 1966)

TIMAC (Time Compression Analog Correlator) is a real-time cross-correlation signal processor. This report summarizes a study made to compare TIMAC with other forms of correlation processors.

27) "Signal-to-Interference Performance of Several Waveforms Considering Sonar Medium Effects", J. Reddeck (July 1966)

Several candidate waveforms for bottom bounce operation are compared in signal-to-noise and signal-to-interference performance.

28) "A Program to Contour Map a Two-Dimensional Array", J.M. Jackson (August, 1966)

Computer programs are described that have been used to generate a contour map of a rectangular two-dimensional array of (computed) data. Some examples are presented. Programs which have been used to generate perspective sketches of the same data surface are also described.

These programs are coded in the Fortran IV Compiles Dialect for Version 13 of IBM's IBSYS system monitor and have been run on an IBM7094. The plots were made on a CALCOMP plotter Model 564.

29) "The Comparative Performance of an Adaptive CW Receiver and a Deltic FM Receiver for the AN/SQS-26 Sonar", J. H. Donegan and W. B. Dowell (September 1966)

A CW transmission, processed by the recently developed "Adaptive Notch Filter Receiver" is compared side by side with an FM waveform processed by the ship's Deltic correlator.

30) "A Logarithmic Receiver for Surface Duct Sonar", J. H. Donegan, W. B. Dowell, and C. Sabato (October 1966)

This report gives a detailed description of the design criteria for a logarithmic receiver and shows the results of a side-by-side comparison test with an AGC receiver.

31) "The Complex Representation of Signals", Dr. T. G. Kincaid (October 1966)

The purpose of this report is to derive and assemble for reference some useful properties of the complex representation of signals.

32) "Memorandum on Reducing ODN Errors for Speed and Course Changes", J. R. Pratt (November 1966)

33) "High Resolution Sonar Signals in a Multipath Environment", (IEEE Transactions on Aerospace and Electronic Systems, November 1966) by S. M. Garber (November 1966)

A model is postulated for the overall spreading of the signal seen at the receiver in which the magnitude of time spreading and doppler spreading are represented by L and B. Detection performance of signals with large pulse length (T) and bandwidth (W) is derived as a function of WL and BT.

34) 24th Navy Symposium on Underwater Acoustics (December 1966)

The following three papers were presented at the 24th Navy Symposium on Underwater Acoustics, (December 1966):

"An Adaptive Notch Receiver for CW Sonar", J. H. Donegan

In long range search sonar, detection of high doppler targets is provided by the use of a long CW pulse and receiving system. Reverberation rejection is accomplished by the use of a fixed notch filter that may be switched out when the background becomes noise limited. Results of the study indicated that a considerable improvement in detection was possible by the use of an "adaptive" inverse filter that varies in depth, shape, and center frequency as the reverberation level fades into the background noise.

"Correlation Loss Measurements of Linear FM Echoes", R. L. Lavallee

The purpose of this paper is to present results showing the observed processing gain which can be obtained from the coherent processing of linear FM coded waveforms in a sonar environment. The results presented here are those obtained from a digital computer analysis of actual sea data.

"Results of One-Way Propagation Measurements over the SQS-26 Bottom-Bounce Path", D. W. Winfield

The primary concern of this investigation is to determine from sea data the effects of the bottom bounce channel on the AN/SQS-26 one-way bottom bounce transmission. Time spreading effects (multipath) are analyzed from 2-ms CW pulses and frequency spreading effects are determined from analysis of 0.5 second CW pulsed transmissions.

35) "Fast Fourier Transform Method", H.J. Scudder, III (December 1966)

This report gives an algorithm and several computer programs for computing the Fourier transform of a set of data, using the method of Cooley and Tukey. This method allows computation to be done in a time proportional to N Log N instead of N^2. A conventional program computing the Fourier transform for 8192 data points has been reported to take 30 minutes on a 7090 as opposed to only 8 seconds using this method.

36) "Data Acquisition and Analysis Notes for CX R/M Test", Dr. J.P. Costas et. al. (March 1967)

In accordance with contract requirements tests must be made on the AN/SQS-26 CX sonar system to determine reliability, maintainability, and availability. This report describes the work performed by the Advanced Projects Development Operation of HMED in support of this test program.

37) "Comparison of the Detection of Zero Doppler FM and CW Sonar Echos in Reverberation and Noise (Sea Data)", R. L. Lavallee (March 1967)

The detection performance of three basic sonar signals - a simple pulse (CW), a linearly frequency modulated pulse (LFM) and a pseudo-random frequency modulated pulse (PRFM) - under sea conditions having an "abnormally" high reverberation level is examined working with a manuevering target. A few models are analyzed to note the effect of incoherent post-detection integration as an attempt to recombine multiple resolvable arrivals.

38) "Use of Post-Detection Integration to Recombine Multipath at the Correlator Output", R. L. Lavallee (April 1967)

This report investigates the use of post-detection integration to recombine multipath at the output of a TIMAC correlator using laboratory generated signals and multipath. The detection performance obtained in the laboratory is compared with theory.

39) "Processing with Conventional and Optimum Acoustic Arrays", Dr. A. M. Vural (April 1967)

The purpose of this work is to analyze the performance of conventional (linear or non-linear), optimum, and some simple adaptive phased arrays subject to space-time fields. The Class of space-time fields considered includes: deterministic or random signals; correlated, non-homogeneous noise, coherent interference and reverberation (or clutter). In the analysis beam patterns, directivity indices, space-time output correlation functions, and signal-to-noise (interference, reverberation) ratios are utilized as performance criteria.

40) The following reports have been issued in conjection with the AN/SQS-26 Signal Processing Study Contracts by Project Personnel of the Advance Sonar Development Subsection.

Vol. I --- SOFIX Signal Processing Evaluation (NObsr-75240) - Final Results - 7/10/67
Vol. II --- SOFIX Signal Processing Evaluation (NObsr-75240) - Monthly Progress Reports (May 1963 - February 1965)- 5/16/67
Vol. III -- AN/SQS-26 Signal Processing Study (NObsr-93137) - Final Results - 7/10/67
Vol. IV -- AN/SQS-26 Signal Processing Study (NObsr-93137) - Monthly Progress Reports (June 1965 - November 1966) - 6/13/67
Vol. V --- AN/SQS-26 Signal Processing Study (NObsr-93137) - Data Appendix - 6/16/67

41) "AN/BQR-7 DIMUS/Towed Array Program -- Final Report" (June 1967)

The purpose of this study was to integrate the aft looking capability of the General Electric AN/BQR-7 DIMUS detection system. The equipment required to accomplish the integration was conceptually designed, specified, and fitted into a reliability model.

APPENDIX

New Display Format and a Flexible-Time Integrator for Spectral-Analysis Instrumentation

DAVID E. WOOD

Advanced Technology Laboratories, General Electric Company, Schenectady, New York

(Received 8 January 1964)

Continuing development has increased the capabilities of the spectral-analysis instrumentation reported earlier [D. E. Wood and T. L. Hewitt, J. Acoust. Soc. Am. 35, 1274–1278 (1963)]. This analyzer operates in real time by very rapid scanning of the outputs of a bank of bandpass filters. A unique process of true interpolation generates continuous spectral cross sections that preserve accurate frequency relations of signal components. The cross sections are recorded on strip film by photographing their display on a CR tube. Spectrographic-picture formats previously described include complete cross-section records and spectrograms showing amplitude by intensity-modulation. A new display technique clarifies frequency patterns by marking just at the amplitude maxima or "peaks" in spectral cross sections. The simplified picture of the spectral "hilltops" pinpoints the frequencies and frequency modulations of features such as speech formants. This binary type of picture requires no grey scale and improves the resolution of small features. The "peak" display may be combined with other formats by means of a selector–combiner device. A novel analog integrator now provides flexible time-averaging by adding spectral cross sections in numbers variable from 2 to over 1000. The periods of averaging can be overlapped and the integrator could be equipped to provide simultaneous multiple outputs representing different averaging periods. The analyzer system is organized to take full advantage of the various kinds of flexibility with a minimum of operational steps. The combination of simple control, real-time operation, and strip-film recording provide the capabilities for large-scale investigations, while flexibility of analysis and display increase the information to be seen in the spectrographic pictures.

INTRODUCTION

A NEW instrumentation for making spectrographic pictures of speech was described in a previous article.[1] This instrumentation performs spectral analysis in real time and records the results on photographic strip film. A block diagram of the basic functions of analysis is repeated here in Fig. 1. Incoming signals are heterodyned to an intermediate frequency range. The function of frequency division is performed by a bank of filters. These are rapidly scanned by a unique process that interpolates the filter outputs to create continuous cross sections of amplitude versus frequency. These cross sections are then subjected to a logarithmic compression to render patterns insensitive to amplitude over approximately a 50-dB range. Spectrographic-picture formats previously described include records of complete series of spectral cross sections as amplitude versus frequency curves and spectrograms representing amplitude as "Z"-axis modulation of the film exposure. The range of frequencies to be analyzed can be shifted by changing the frequency of the oscillator used to heterodyne the input to the intermediate frequency range of the filters. Effective filter bandwidths can be changed by playing tape recordings of signals at higher or lower speeds than the original recording condition.

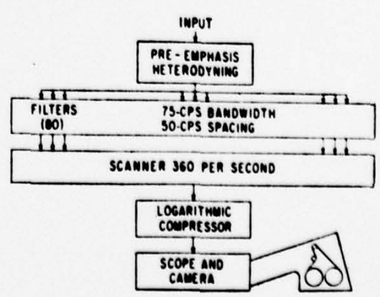


FIG. 1. Spectral-analysis system.

[1] D. E. Wood and T. L. Hewitt, "New Instrumentation for Making Spectrographic Pictures of Speech," J. Acoust. Soc. Am. 35, 1274–1278 (1963).

Spectrographic pictures, such as those supplied by the familiar Sonagraph, have become widely accepted as a useful tool for discovering informative relations in acoustic signals. The kinds and quality of information that the educated viewer can find in spectral pictures depends both on the functions of analysis and the form of the picture. The needs to optimize information recovery at all stages inspired and directed the development of the instrumentation previously reported and the additional features described in this article. One of the new features is a display format conceived to clarify the patterns formed by "peaks" of amplitude in the spectral cross sections. A second feature is a novel device for flexible time-averaging of the short-time spectra to provide matching of features that persist appreciably longer than the transient response time of the bandpass filters.

I. PERCEPTUAL ENHANCEMENT BY DISPLAY OF SPECTRAL AMPLITUDE PEAKS

Spectrograms are as useful as the value of the information conveyed to the human viewer. A very familiar type of speech spectrogram has been the presentation of amplitude as picture-density modulation in a format of frequency versus time coordinates. An obvious limitation in such spectrograms is the lack of sensitivity to spectral features represented by relatively small differences in amplitude. In consequence, it is often difficult to determine the precise frequencies at which energy peaks occur and some features may be altogether lost. Since the rather exact frequencies of amplitude peaks such as speech formants are prime information code cues, it seemed worth while to develop a display technique that emphasized this type of feature.

Accordingly, circuits were developed that automatically detect each maximum during the generation of spectral cross sections by filter-scanning and interpolation. These spectral "peaks" are recorded on film by brightening a cathode-ray-tube trace, with short pulses initiated at each maximum amplitude as shown in Fig. 2. To provide a rough indication of amplitude, the length of these pulses can be made proportional to the logarithm of the peak amplitudes.

The "peak" display sharpens the presentation of patterns such as the regularities of speech-formant resonances and the irregularities of fricative noise. Such a display is reproduced in Fig. 3 with an intensity-modulated spectrogram for comparison. Quite precise values of frequency can be read from the peak pictures by noting where the lower side of a band or mark occurs. A particular virtue of the peak display is its sensitive indication of frequency modulation with an accurate indication of the size of frequency shifts. For example, in Fig. 3 the frequency excursions of formant energy are a conspicuous feature. As can be seen, second and higher formants generally exhibit a limited (but not negligible) upward shift of the energy peak during each glottal period. The first formants exhibit a startling pattern of very large periodic movements of energy peaks from values near the voicing fundamental frequency to a resonance location. This dynamic character of energy in the first-formant region can confuse people or circuits in attempting to identify accurate values of the resonant frequency. This particular figure represents analysis with about 150-cps-filter bandwidth—sufficiently wide to reproduce transient conditions within voicing periods of the adult male voice. Similar pictures of adult female voices analyzed with 300-cps bandwidths have revealed the same type of transient patterns. It seems pertinent to note that narrow-band analysis that resolves the pitch harmonics may eliminate the evidence of these frequency shifts. The more-static narrow-band spectral cross sections appear to show first-formant position clearly, but one can raise a question as to how the frequency shifts within glottal periods affect the averaging of energy over a period or more.

The peak displays have proved most useful not only for speech investigation but for the analysis of other types of signals. New information has frequently been discovered first in the peak displays. In some signal studies at this laboratory, this new display has entirely replaced intensity-modulated spectrograms. However,

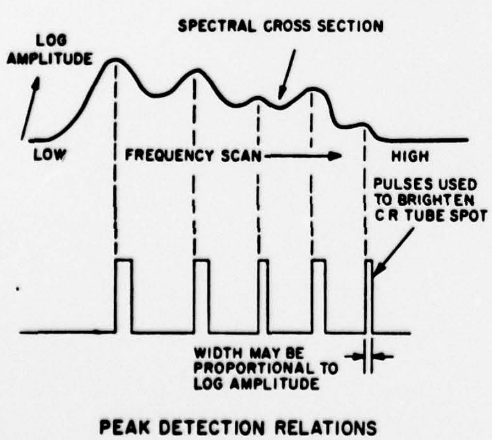


FIG. 2. Spectral cross section.

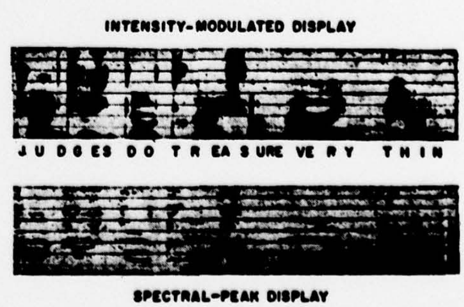


FIG. 3. Comparison of spectral displays.

impulsive events such as stop-consonant bursts seem better represented in the conventional intensity-modulated format, so there is need for both displays. In fact, experience to date suggests that any signal coded as complexly as speech requires flexibility of both display and analysis to reveal different kinds of information.

II. FLEXIBLE TIME INTEGRATOR

The output of filtering and interpolative scanning in this instrumentation is in the form of spectral cross sections, each representing information contained in the momentary distribution of energy in the various bandpass filters. Since the signal storage time is just that of the filters, a very high time resolution is achieved. However, many informative components of signals have durations longer than the filter storage or "integration" period when the bandwidth is properly matched to the frequency resolution desired. In general, a signal component will be most clearly defined if the spectral patterns are averaged over a period matching the time that the component is effectively stationary in frequency. Such time-averaging can enhance constant-frequency components relative to random-noise components and average out short-time amplitude fluctuations. In response to this need, a flexible time-averaging device has been developed for use with the spectral-analysis instrumentation.

A conventional bank-of-filters analyzer of the vocoder type performs frequency divisions with bandpass filters, each followed by an envelope detector and low-pass filter as indicated in Fig. 4. The effective time constant of the low-pass filter determines the averaging or integration time. Because of the exponential decay of energy stored in the averaging networks, the transiently stored signal is weighted in a varying fashion, depending upon its time of arrival relative to the instant of sampling

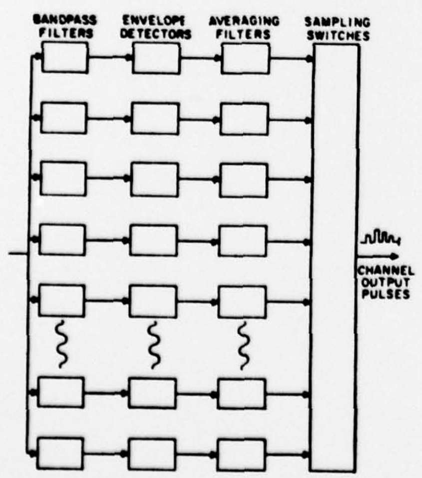


FIG. 4. Vocoder-type frequency analysis.

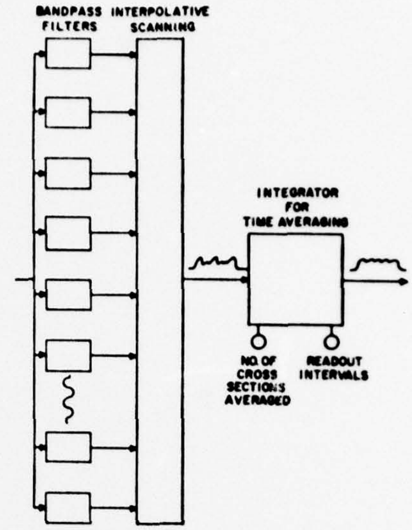


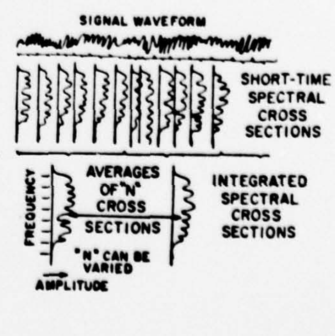
FIG. 5. Frequency analysis and integration in new instrumentation.

the channel output. The parameters of the individual networks for each filter would have to be changed to alter the averaging time.

Quite a different approach is taken in the ATL analyzer to achieve variable integration times. There are no detectors and no low-pass filters after the bandpass filters. Instead, the IF signals from the filters are directly scanned and interpolated to create spectral cross sections, as shown in Fig. 5. Only the storage time of the bandpass-filtering is effective up to this point, and a high sampling rate insures adequate preservation of the transient response of the bandpass filters. Additional time-averaging is performed in the separate device, which is labeled "Integrator" in the diagram. The analog-type integrator stores and sums spectral cross sections, providing averaged cross sections as indicated in Fig. 6.

The integrator possesses some very useful flexibilities. The number of cross sections added can be varied in many steps from a minimum of 2 to a present maximum of over 1000. This allows the user to explore rapidly the effect of integration time upon acoustic relations and to optimize averaging periods to clarify particular features. (Summing 100 cross sections represents about 140 msec

FIG. 6. Signal waveform.



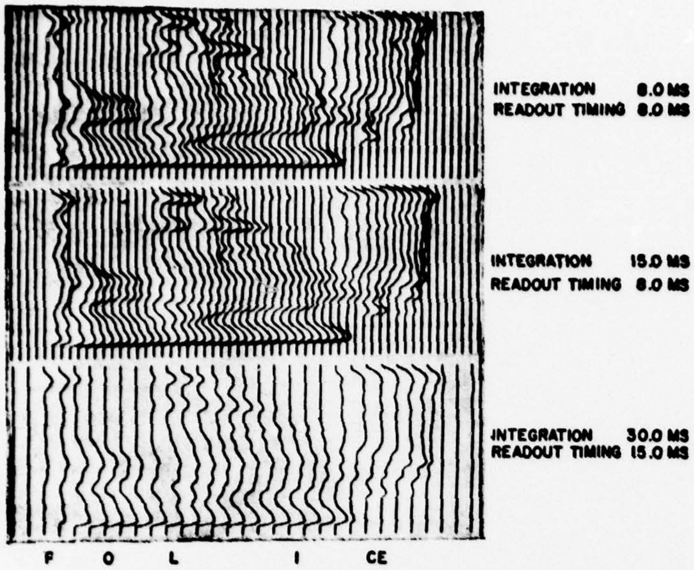


FIG. 7. Integrated cross sections.

when analyzing with 150-cps-filter bandwidth, or 70 msec for 300-cps bandwidth.) Another flexibility is the capability of generating running averages. It is possible to drop out one or more of the oldest cross sections and add a corresponding number of new cross sections to generate averages that cover overlapping periods of signal. This overlapping can both increase the information recorded and provide better proportioned visible patterns. A related potential capability is the provision of multiple outputs representing different averaging periods. All cross sections are given equal weighting in this integration process. Thus, the period of integration is more clearly defined than is the case where smoothing networks respond to signals with exponential-type buildup and decay.

Two illustrations of integration are included here. Figure 7 reproduces cross sections for the word "police" generated with three different periods of averaging. There was no overlapping of periods for the 8.0-msec integration, but the 15- and 30-msec were read with approximately 50% overlap of periods. The effects of different averaging times can be studied in detail, using the cross-section records. However, many qualitative relations can be perceived in spectrograms such as Fig. 8. This figure represents the same utterance with 3 averaging times, using the peak display format to clarify the effects of integration. In the top section, the speech has been analyzed without use of the integrator so that the storage time of the bandpass filters is the only source of averaging. In the middle frame, five cross sections were summed and, in the bottom, eleven were summed. Running averages were used here to insure the maximum recovery of information. Analysis was done with 150-cps bandwidth. One effect of integration is to enhance features that are persistent in amplitude and remain an appreciable time within a frequency-resolution element of the filtering. Thus, in the noiselike fricative sounds such as the "ch" of *which* "ce = s" of *police*, increased time-averaging clarifies the location of resonances in the sound spectrum. On the other hand, rapid fluctuations are averaged out. Thus, the frequency modulations in the formants are smoothed out as the integration time becomes appreciably longer than a glottal period. Increased time-averaging can also cause a "smearing" of short transients such as stop-consonant bursts. In fact, brief impulsive events are generally poorly represented by overly long integration, as further illustrated by the loss of the weak second-formant impulses in the "O" of *police*.

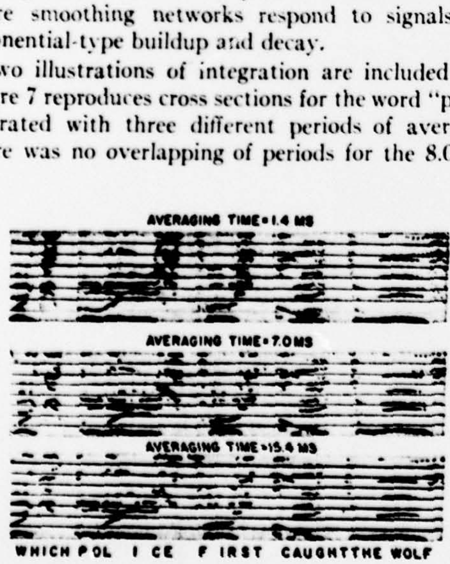


FIG. 8. Effects of different averaging times shown by display of spectral peaks.

The function of time integration has been made as flexible as possible in recognition of the fact that there are many different "optimum" conditions for feature-matching. Easy availability of a wide range of integration times has proven a very useful capability in the exploration of classes of signals ranging from biological

phenomena, such as speech to the sounds and vibrations of mechanical sources.

III. ANALYZER ORGANIZATION

The analyzer controls are organized so that an operator can select any available combination of functions by switching. This convenience is essential to the economical use of so flexible an instrument lest the user be burdened with confusing and time-consuming reconnections and settings with their attendant probabilities of errors in performance. Fortunately—and not entirely by accident—the various functions of analysis and display are performed in a serial fashion so that operations can be easily bypassed or parameters manipulated within a single element of the chain. The serial nature of the system and principal types of control are made apparent in Fig. 9.

The elements of analysis and the nature of the flexibilities of the system have been described except for the "selector-combiner" used to establish the display types singly or in combinations. For example, it is possible to generate intensity-modulated spectograms with "spectral peaks" marked either by darker marks or by blanking the CR trace to produce gaps in the features on the display. Similarly, on records reproducing the cross sections as plots of amplitude versus frequency, it is possible to employ amplitude-level markers, frequency markers, intensity modulation, and sometimes peak markers to correlate with peak displays. A particularly useful combination for speech has been intensity-modulation plus a very small amount of amplitude-deflection to produce a "super spectrogram" with more-dramatic portrayal of amplitude transients and a relative sharpening of formants and other energy concentrations.

IV. CONCLUSION

This instrumentation was developed to be a tool for exposing to human perception and intelligence the information-bearing quantities in acoustic signals. It was intended that the spectral analysis should reveal both fine details and larger patterns as needed. Accordingly, flexibility of analysis parameters was a paramount design objective. The recent addition of a flexible time integrator rounds out the fundamental capabilities needed to match both time and frequency relations in many combinations.

In addition, means have been sought to improve the transmission of information from picture to the human

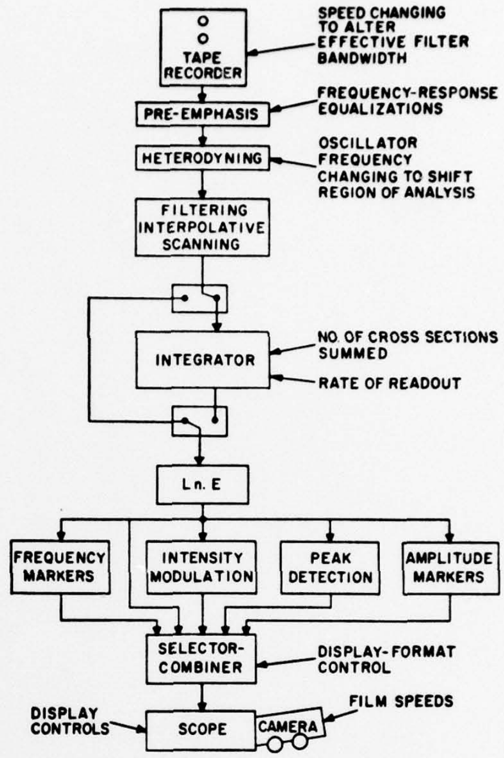


FIG. 9. Flexibilities of analyzer operation.

intelligence. Many experiments have been carried on in display formats and predisplay processing. A particularly successful technique has been the so-called "spectral-peak display." This display presents the location of the various maxima or "hilltops" in the frequency distributions eliminating all other response to clarify this essential type of pattern. The "peak" pictures have particular virtues of being sensitive indicators of small distinctions that are lost in intensity-modulated spectrograms. Proof of the worth of this type of perceptual enhancement has been the frequent discovery of new information in the spectral patterns.

Real-time operation and recording combined with the other performance capabilities make this an excellent tool for large-scale investigations of many classes of signals. The analysis capabilities are proving increasingly useful in solving practical problems requiring spectral analysis of signals.

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